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PHYSICAL GEOGRAPHY FOR INDIAN STUDENTS

PHYSICAL GEOGRAPHY

FOR

INDIAN STUDENTS

BEING A COMPLETELY REVISED AND ENLARGED EDITION
OF SIMMONS AND STENHOUSE'S "CLASS-BOOK
OF PHYSICAL GEOGRAPHY"

BY

CYRIL S. FOX

D SC, M.I MIN E, F G.S., GEOLOGICAL SURVEY OF INDIA

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PREFACE TO INDIAN EDITION

It is now generally recognised that elementary knowledge of physical geography is an essential part of the study of the earth in relation to man, which defines the scope of geography. For a long time I have thought that a suitable class book was needed on the subject, written particularly for Indian students, and similar to that charming book "The Rudiments of Physical Geography for the use of Indian Schools" written more than sixty years ago by Henry F. Blanford, F.R.S., originally of the Geological Survey of India and afterwards Director of the Indian Meteorological Department. Although it was last revised in 1884 it is still a valuable book ; and long ago I resolved to approach Messrs. Macmillan & Co. with the proposal to prepare an enlarged edition of it.

I had already seriously settled down to make notes and collect suitable illustrations for a new book on Physical Geography for Indian students when Sir Frank Noyce, the late Member for the Department of Industries and Labour of the Government of India, suggested that I should bring Blanford's book up-to-date. Consequently, when, in 1935, Sir Richard Gregory, F.R.S., wrote to the Director, Geological Survey of India, asking if one of his officers would undertake the revision of the geological portion of Simmons and Stenhouse's well-known book, "Class Book of Physical Geography", the inquiry was referred to me. In the new syllabus of geography for the First Year Arts Examination of the University of Bombay issued towards the end of 1935, it was suggested that the standard and work and manner of treatment of the parts of the subject belonging to physical geography should be as in Simmons and Stenhouse's book ; and this provided a particular reason for the revision and extension of the book so as to adapt it to the requirements of Indian schools and colleges.

Though it was originally suggested that I should confine myself to the task of making suitable changes in the geological and related sections to render the book suitable for Indian students, after I had accepted I immediately communicated with Sir Richard Gregory offering to carry out the work for the whole book if the other portions had not already been allotted elsewhere. After the entire work had been entrusted to me I felt that perhaps a better book might be prepared if it was completely re-written. With this end in view I asked several of my colleagues and other friends to assist by writing special chapters or sections where their knowledge was considerable, but I meanwhile continued the task which had been undertaken by me. Unfortunately, when the work had progressed far enough for a final choice between the two, I was obliged to admit that the revised Class Book would prove more suitable for use in Indian schools and colleges than the more elaborate I had in mind. I need scarcely say how grateful I am to my friends for what to them may appear as wasted labour, but it is my hope that in the near future their contributions may be fully utilized; meanwhile, I have drawn much upon the valuable material they had prepared.

Among those who so generously prepared chapters, etc., for the contemplated new book I am specially indebted to my colleagues Dr. Henry Crookshank, Dr. A. L. Coulson, Mr. D. N. Wadia, Dr. J. A. Dunn and Mr. J. B. Auden. I am under a similar obligation to Dr. Baini Prashad, Director, Zoological Survey of India, and to Brigadier Sir Harold Couchman, D.S.O., R.E., the late Surveyor General, who most kindly supplied me with a history of the Survey of India. The Surveyor General has further assisted the revised book in a very generous manner, by providing, at a nominal charge, the coloured Figs. 26, 29, 31, 41 and 43, which illustrate typical maps issued by the Survey of India and the map symbols employed on all such maps. These illustrations were specially prepared for this book in the Survey of India Map Office at 13 Wood Street, Calcutta. I have also to acknowledge the use of Figs. 33, 34, 266 and 267, which have been taken from recent reports of the Geodetic Branch of the Survey of India. It is a great pleasure also to acknowledge the kindness of the Indian Air Survey and Transport Ltd., Dum Dum, for permission to use information and illustrations provided by them—Figs. 55, 56 and 116—for this book. The American Book Company of New York have very courteously allowed me to reproduce several illustrations from Todd's " New Astronomy ". Holmes Bros., of Peshawar, generously permitted the publication of Fig. 30, and Kinsey Bros., of Mussoorie and Delhi, have not only granted their sanction for the reproduction of Fig. 226, but also generously supplied the details relating to it. Hands & Co., of Jabalpur, do not now appear to exist or else I am sure they would have approved of my using Figs. 103 to 106 and 183, which I purchased from them twenty-five years ago. It is again a pleasure to acknowledge the ready assistance of The Statesman Ltd., Calcutta, for providing Fig. 124, which I selected from their excellent collection of photographs.

Dr. A. M. Heron, Director, Geological Survey of India, has not only encouraged me in the preparation of this book by placing the official collection of photographs at my disposal, but was also prepared to write a chapter for the new book should it be chosen for publication instead of the revised Class-Book now issued. Figs. 186 and 187 were drawn in the office of the Geological Survey of India, and it will be seen that a very large number of official photographs have been used in illustrating this book. Dr. S. K. Pramanik, Indian Meteorological Department, Alipur, most kindly prepared several charts and a description of the Cocanada cyclone of the 17th October, 1933, and it is from his material, so generously supplied, that Fig. 261 and my description have been taken. Captain Galloway, British Legation, Kabul, has kindly allowed me to reproduce Fig. 190. The illustration shown in Fig. 192 is from a photograph by Mr. F. Ludlow, with whose kind permission it is reproduced. This illustration appeared in the *Geographical Journal*, and the editor has, I understand, given his permission for its reproduction in this book. It is impossible to name all who have assisted me in one way or another as I am conscious of so much kindness, but I cannot conclude without recording my indebtedness to my wife for giving hours of her time, while we were on leave, in reading over the manuscript, making the typescript and assisting in numerous other ways.

Finally, I must gratefully record the close attention and immediate assistance I have at all times received from Sir Richard Gregory and Messrs. Macmillan & Co. Ltd. generally in regard to matters of proofs and illustrations. Instead of being a task the work has been a pleasure, and I can say that I have never received such faultless proofs and so much *press* assistance as I have from Messrs. Robert MacLehose & Co. Ltd., of Glasgow.

I gladly acknowledge all the help which has been afforded me in the preparation of this revised and enlarged edition of this " Class Book of Physical Geography for Indian Students". I trust that the book will not only supply the need for a text-book in Indian schools and colleges, but also that Indian students will find it both informative and a pleasure to study.

The Director, Geological Survey of India, very kindly gave me permission to carry out this work, and permitted Mr. M. S. Venkatram to undertake the preparation of the Index which he has so painstakingly done.

CYRIL S. FOX

PART I

MAP-MAKING AND ASTRONOMICAL GEOGRAPHY

CHAPTER I

THE MEANING OF A MAP

1. THE POINTS OF THE COMPASS

1. Experiments with a pocket magnetic compass.—Procure an ordinary pocket compass, lay it flat on the table and examine it. Turn the compass round, still keeping it flat; does the needle move too, or does it remain pointing constantly in one direction? In which direction is the sun about midday? One end of the needle points nearly in this direction, which is called south. Set the compass in such a position that the point marked *S* on the card is just under the south-pointing end of the needle, and consequently that marked *N* just under the north-pointing end. The letter *E* is in the direction of east, *W* of west, etc. Learn also the terms used for the various directions intermediate between these chief " points ". If possible, study also a mariner's compass in the same way and note that the circle of 360° is divided into 32 "*points*" of 11¼° each and lettered in a special way (Fig. 3).

2. Determine the directions, expressed in these terms, in which several objects in the room lie, relatively to the position of the compass. In what directions do the various windows of the house look? Which of them get the sunshine in the morning, at midday, and in the afternoon respectively? Note the direction of such buildings as can be seen from the windows of the room. Make a note of the directions in which the principal streets in your neighbourhood run. See especially if the compass needle points to the Pole Star at night. If there is a difference, note whether the needle points slightly to the west or east of the Pole Star. By ascertaining this we find the " error " or declination of the compass for the place where the observation is made.*

3. True north.—Pin a sheet of drawing-paper on a drawing-board, and place the board flat where the sun will shine full on it at midday. If necessary level the board, that is, render it quite horizontal, by packing paper under the edge until a steel bicycle-ball does not roll about when placed on the board. Now stick a darning needle upright in the paper at the edge nearest the sun. Make sure that the needle is vertical by looking at it from different points of view. About 11.30 a.m., draw an arc of a circle on the paper, taking as centre the foot of the needle and as radius the length of its shadow. At once mark on the arc the point where the end of the shadow cuts it. Notice the slow movement of the shadow over the paper, and when its end once more lies exactly on the arc, mark its position. Now remove the needle,

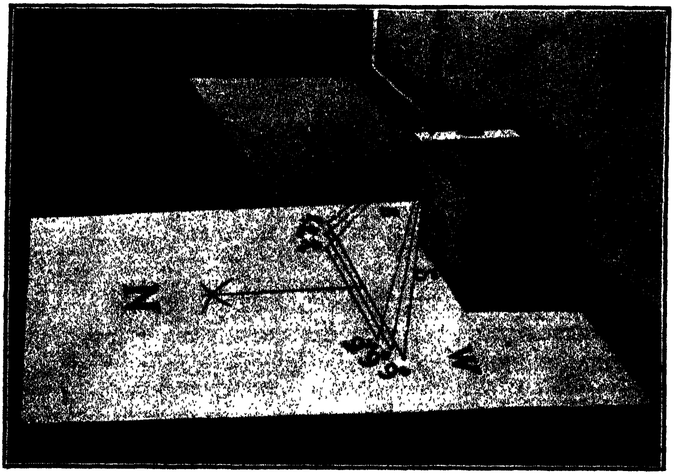

FIG. 1.—Indoor method of finding the True North by using a beam of sunlight. (Adapted from Todd's " New Astronomy " with the permission of the American Book Company, New York.)

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* In most places in India the magnetic declination is so small that the direction of the compass needle or magnetic north is practically the same as the true or geographical north.

but leave the drawing-board in position. Draw straight lines from the centre of the arc, *i.e.* the point where the needle stood, to the two marked points on it, and bisect the angle between them. The bisecting line is in the true north and south direction.

Another way to do this is shown in Fig. 1.

4. On another day fix the needle vertically in a different part of the board, and at intervals of half an hour throughout the day (if the sun be shining) make a dot on the paper at the end of the shadow. Join the dots by a smoothly curved line. This curve is known as a ***shadow trace***. With the foot of the needle as centre draw an arc of a circle cutting the shadow trace twice. Draw straight lines from the points of section to the centre of the arc, and bisect the angle between them as before to find the north-and-south line. If you have not seen a sun-dial make a point of examining one at the first opportunity.

Of the two methods of finding the true north that you have tried which method, 3 or 4, would you select on a cloudy day? Why?

5. **Error of compass.**—Place your pocket compass on the north-and-south line thus obtained, so that the centre of the compass is exactly on the line. Does the needle lie along the line or at an angle with it? Does the north end point eastward or westward of true north? Estimate by the help of a protractor, the angle which the needle makes with the line. This angle is called the " magnetic declination ". This was mentioned in Expt. 2, but it is very important to verify the " error " of the compass. It is sometimes preferred to use the term, " deviation of the compass " instead of " magnetic declination " (Fig. 3).

6. **How to use a watch as a compass.**—Lay your watch face up on a horizontal surface, and turn it until the hour-hand points to the sun. The hand will then exactly overlie its own shadow. The line bisecting the angular distance between the hour-hand and XII will point southward. This is suitable for any place north of the equator. In the southern hemisphere the hour 12 or XII is to be pointed to the sun and the line bisecting the angle between the hour hand and XII will point to the north.

7. **To draw a north-and-south line in the playground.** (*Outdoor work.*) —Using the method of Expt. 4 above, mark the shadow trace of the top of a convenient pole. If the end of the shadow be indistinct, mark it as accurately as you can—three or four times at minute intervals—every half hour or so, and in each group take the mean position as the correct point. Complete the shadow trace and then draw the circle with chalk held at the end of a cord which is tied loosely to the pole.

Bisect the angle as before and extend the bisecting line as far as possible and mark the end with a wooden peg. This line from the post to the peg is roughly the north-and-south line. Check your compass along this line to determine its deviation or so-called " error " or declination.

8. How to find the pole-star. (*Outdoor work.*)—On a clear night look in the northern sky for the group of seven stars called the Plough, forming part of the Great Bear (*Ursa Major*) ; identify them by comparison with Fig. 4. Two of these stars are called the " pointers " because an imaginary line joining them passes, if produced, close to the Pole Star. Find the Pole Star. Observe it at different hours of the night and at different times of the year, and notice that it is always in the north, although the position of all other visible stars varies (Fig. 5).

The importance of maps.—In every branch of geography constant use is made of diagrams called maps. Most commonly a map represents in a conventional manner a portion of the earth's surface, somewhat as it would be seen by an eye directly above it, but with additions which render it a summary of observations and surveys made on the spot. Such a diagram is of the greatest value, because it enables a student quickly to understand what are the most important features of the region which is being studied, and how these features compare with each other in size and position ; besides this, it gives a vivid impression of many other facts which could be only learnt slowly and with much trouble by any other means. It is plain, therefore, that the ability to " read " a map intelligently is one to be cultivated without delay, and there is no surer way by which this power may be acquired than by learning how to construct simple maps.

The points of the compass.—Very little thought will show that in any attempt either to describe or to draw the position of a place, some means of referring to its direction is necessary. We may in ordinary conversation say, for example, that a certain building is on our right, but it is clear that the statement depends on our position at the time, and is true only so long as we remain in that position. When we wish to refer to direction in language which is always true, however, we say that one place is to the north, the south, the east, or the west (as the case may be) of another. This is a much better method, because the statement does not depend on the position of something which may change. How, then, can these directions be recognised ?

One of the simplest ways is by the help of a **compass needle.** This is a thin bar of steel which has been made into a magnet, so that when mounted on a pivot it can turn freely in a horizontal plane (Fig. 2).

All magnets, if suspended so that they can move from side to side freely, arrange themselves so that one end, called the north-seeking end, points in the direction of north. The other end of course seeks the south. It is this fact which is made use of in the ordinary compass needle which is used in geographical study for the determination of direction. The line along which the magnet arranges itself is called the **magnetic meridian.**

A person whose face is to the north has his back to the south, his right hand to the east and his left hand to the west. A pocket compass (Fig. 2), such as is sold by opticians, is provided with a card showing the directions of the various **points of the compass** when the north end of the needle is over the letter *N* on the card. Points intermediate between the four principal points have such names as north-east (marked *NE*), west-south-west (marked *WSW*), etc., (Fig. 3), and, as there are 32 such lettered divisions, each of $11\frac{1}{4}°$ known as points of the compass, and each can be subdivided into quarter points of $2\frac{13}{16}°$ each, it is possible in these terms to express direction with considerable accuracy.

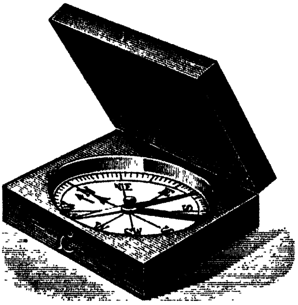

FIG. 2.—A pocket compass.

The **mariner's compass,** though on the same principle, is provided with special means of suspension, etc., to allow for the motion of the ship and other disturbances to which it is subjected. Some surveying compasses have the graduated card divided into 360°, clockwise, so that due east is 90°, due south is 180° and west is 270°, while the north point is 360°, or 0°. **Prismatic compasses** are elaborate and are graduated from the south as 0° or 360°, in a clockwise direction.

This is because the readings are observed through the prism which is at the south end of the instrument. It will also be seen that for the same reason the west point is marked east, or 90°, and the north is marked south, or 180°, and the east is marked west, or 270°.

In India, as already stated, the true north agrees very closely with the direction which is pointed to by a magnetic compass needle, but in England and in other countries the magnetic declination may be as much as 12° or more. For this reason it is necessary to adopt a more accurate (though not quite so easy) way of determining the points of the compass by observing **the position of the sun.** Precisely at midday the sun is exactly in the south. Now the moment of midday does not always correspond with 12 noon as indicated by a timepiece; it is sometimes a little before and sometimes a little after twelve o'clock (p. 111). True midday, however, is the time when the sun is highest in the heavens, and this time may be found by observing when the shadow of a vertical post is shortest. At that moment the sun is exactly in the south, and the shadow is thrown exactly to the north. A little before noon the shadow lies towards the north-west; it changes gradually to the north, becoming shorter and shorter; and then, having passed through the true midday line, works slowly eastwards, becoming longer and longer. The length of the shadow when it lies, say, 10 degrees to the west of true north is exactly equal to the length when, later, it lies 10 degrees to the east of true north; and similarly with any other angle. If, therefore, the direction of the shadow be marked—once before true noon and once after—when it is of the same length, the line bisecting the angle

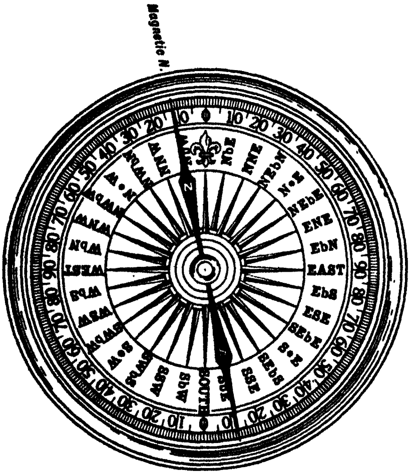

Fig. 3.—To show the "points of the compass", and a magnetic declination of 12° at London.

thus obtained will be the true midday line, running exactly north and south. Such a " midday " or north-and-south line at any place is often called the **geographical meridian** of that place.

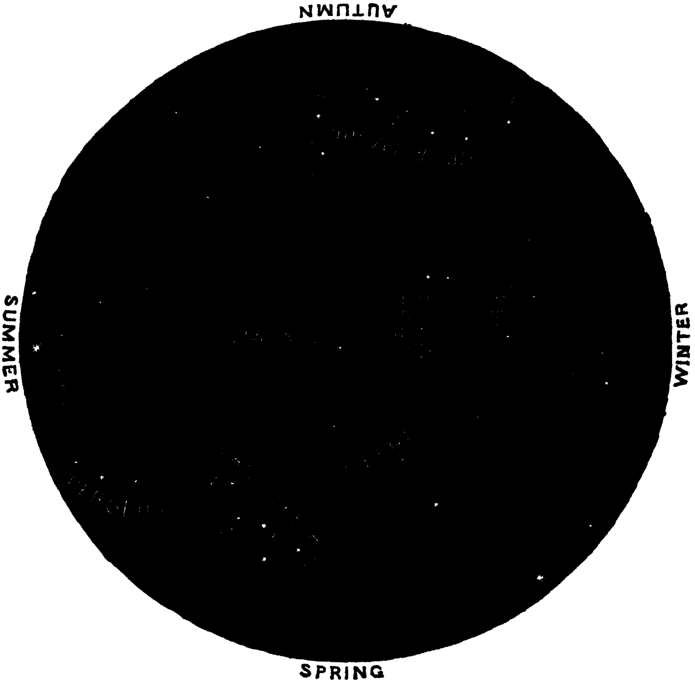

FIG. 4.—View of the northern sky. To find the aspect of the circumpolar constellations at about 10 p.m. during any season of the year, turn the page until the name of the season is at the bottom.

If a line be marked out between two pegs in a true or geographical meridian, *i.e.* north and south, it may be used for determining the magnetic meridian divergence, or magnetic declination, of that locality. It will be necessary only to take a compass bearing, by sighting from one peg to the other, to see if the needle points to 360° (or 180°) on the compass card (Fig. 3). In other words, the geographical meridian does not exactly coincide with the magnetic meridian. The angle between the two meridians is called the

magnetic declination or **variation** of the place. The value of this angle varies from year to year.

A rough, but often useful, method of finding the points of the compass by means of an ordinary watch also depends on the position of the sun. The watch is laid horizontally, face up, and turned until the hour-hand points to the sun. When so placed, the hand just lies over its own shadow on the dial. The watch being held in

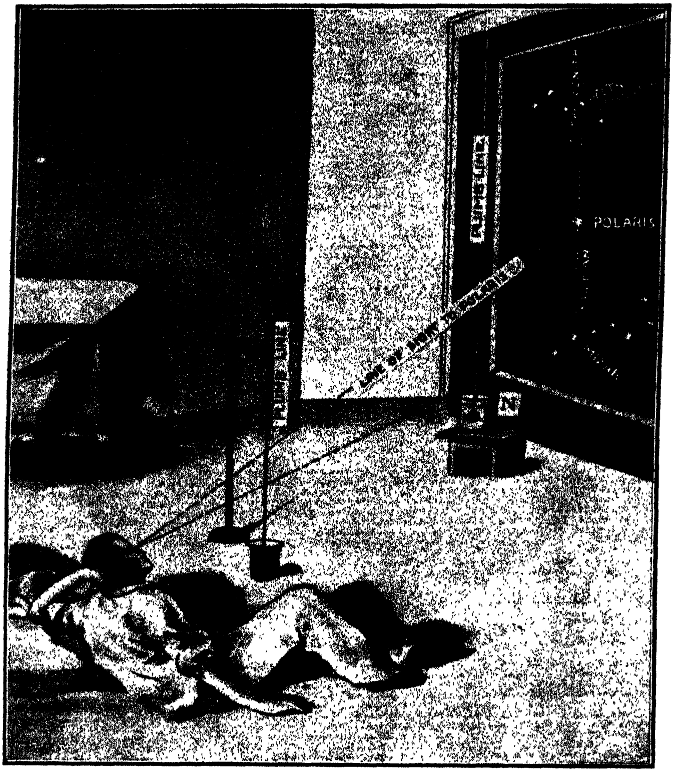

FIG. 5.—Showing the position of Mizar in the Great Bear, and *δ Cassiopeiae* in *Cassiopeia* when the Pole-Star Polaris is on the meridian, *i.e.* due north. (Taken from Todd's "New Astronomy" with the kind permission of the American Book Company, New York.)

this way, a pencil or other convenient rod, placed horizontally so that it bisects the angular distance between XII and the end of the hour-hand, points nearly due south. It would point exactly south if the sun rose exactly in the east at 6 a.m. and set exactly in the west at 6 p.m. The method is most nearly correct on March 21 and September 23, but is accurate enough for general purposes at any time.

The Pole Star.—On a clear night the points of the compass can be determined easily from the positions of certain stars. A star called the **Pole Star** lies almost exactly in the north, and for this reason it is often called the North Star. It is not in itself very conspicuous, but it can be found by the help of seven stars which from their arrangement are called the **Plough** forming part of the **Great Bear** (*Ursa Major*). This group is found in different positions at different hours of the night and at different times of the year, as is shown in Fig. 4, but two of the stars composing it, Dubhe and Merak (α and β, *Ursae Majoris* respectively)—called the " pointers "—are so placed that an imaginary line joining them, and produced in the manner shown, passes very close to the Pole Star itself, which by this means is identified readily. All the stars to be seen in our sky by anyone facing north, appear to travel in circles round a point near the Pole Star once in about twenty-four hours, but the Pole Star moves round a circle so small that we may consider it to remain always in the same position, exactly in the north. The stars seen when facing south also appear to be carried across the sky in circular sweeps, but only parts of their paths are visible to us. The Pole Star is almost exactly on the meridian when the star Mizar (ζ *Ursae Majoris*) is vertically above or below it (Fig. 5).*

2. THE CONSTRUCTION OF PLANS AND SIMPLE MAPS

To construct plans and simple maps it is necessary to have a few instruments for sighting, measuring and drawing. A scale in inches, divided into sixteenths of an inch, with bevelled edges, is useful;

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* As the line joining Mizar to Polaris, the Pole Star, if continued would pass through the star δ *Cassiopeiae*, this star is useful in place of Mizar when the Great Bear is not visible.

also a protractor for marking angles. In addition to these a measuring tape and steel chain with arrows (Fig. 7), as well as a sight vane, or alidade, and a plane-table (Fig. 15) are necessary. A pocket compass, or better still a surveying compass (Fig. 22), is important for land surveys.

1. The plan of a table.—(*a*) Measure the edges of an ordinary rectangular table, and draw on paper a rectangle with sides one-sixth the length of the sides of the table. The drawing is a plan of the table on a scale of one-sixth, or a scale of 2 inches to the foot. Cut out the drawing.

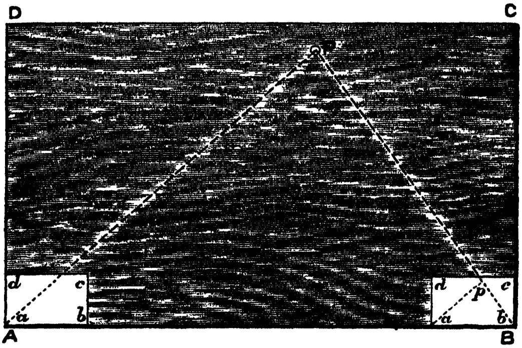

FIG. 6.—Method of drawing the plan of a table. For explanation, see text.

(*b*) Stand a drawing-pin on its head close to one edge of the table; measure the distance of the pin from the nearest corner of the table, and on your drawing make a dot one-sixth of this distance from the corresponding corner, measured along the corresponding side, to represent the position of the pin. Verify the accuracy of the position of the dot, by measuring its distance from the other end of the same side of the rectangle, multiplying by 6, and comparing the length thus obtained with the actual distance.

(*c*) Place the drawing-pin a few inches from the edge of the table, as at *P* (Fig. 6). To represent this position on the plan, lay the drawing on the table so that the point *a* is over the corner *A*, the line *ab* along the side *AB*, and the line *ad* along the side *AD*. "Take a sight" along the surface of the table from *A* in the direction of *P*; make a pencil-dot on the plan exactly between the eye and *P*, and rule a line from *a* through the dot. Now move the plan to the corner *B* of the table, and in a similar manner take a sight of *P* from the point *b*. The intersection of the sighting-lines gives the point *p*, which represents the position of the drawing-pin on the plan.

Notice that in this method of obtaining the point *p*, *a* is placed exactly over *A*, *b* over *B*, and the line *ab* over the side *AB*, so that the " sighting " process is really a method of measuring on the plan the angles *PAB* and *PBA* from the ends of a measured distance *AB*. In actual triangulation and in topographical surveys the same procedure is adopted, but the measured distance *AB*, *i.e.* *ab* on the map, is called a *base line*.

(*d*) Measure the distances *AP* and *BP* with a tape measure, and see if they are just six times the length of *ap* and *bp*. Using a protractor, estimate as accurately as possible the angle which a side of the table, say *BC*, makes with the compass needle, and through the point *B* draw a line making the same angle with the side *BC*. This line will be *NS*. The whole plan should now be placed so that this *NS* line is parallel to the side edges of the paper. As the magnetic and geographical meridians are practically coincident in India the plan of the table, or any other map based on compass bearings, will be correctly placed as regards the true north if arranged as described above.

2. The plan of a room.—(*a*) Draw the plan of a rectangular room, to a suitable scale, by direct measurement, indicating the positions of all corners, windows, doorways and fireplaces. Letter the principal points *A*, *B*, *C*, etc. Take a compass sight along one side or from one corner to the other and estimate the angle or compass bearing of this line. Draw in the *NS* line on the plan of the room.

(*b*) Draw the plan of the same room, to the same scale, by working from a *base line*. This may be one edge of a table or desk placed near the middle of the room. First draw the line representing this edge, to scale, and at the correct angle to the magnetic meridian, as before. Then from each end " sight " convenient points to obtain their directions. For sighting it will now be convenient to use a sight-rule or alidade.* Be careful to observe the precautions taken in Expt. 1 (*c*). Draw each sight-line, and then measure the distance of the point with a tape, and mark its position on the plan, lettering it at once as in Expt.

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* Vertical needles, pushed into the upper surface of the ruler may be used instead if the pin heads cause the ruler to wobble. A better sighting arrangement, easily made, consists of a vertical needle at the far end of the ruler, and at the sighting end a vertical strip of cardboard, sheet zinc or tin, in which a vertical slit has been cut in the manner shown in Fig. 15.

2 (*a*). In cases where the tape will not reach the whole distance to be measured, measure along the floor, using a piece of tightened string to be sure you are keeping to the straight line.

Obtain one or two points on the plan by sighting each from *both* ends of the *base line* and trying whether the point of intersection of the two sighting-lines coincides with the point previously obtained by measuring. This is a good test in checking the accuracy of your work. Notice that by sighting from two points already marked on the plan you can obtain the position of a third point without going to it. You can also find its distance, by measuring the line on the plan and multiplying its length by the scale-number.

3. The plan of a playground. (*Outdoor work.*)—Apply the same method to the drawing of a plan of a playground. First, chalk off a base line, using stretched string to obtain a straight line. If convenient, let the base line lie in the magnetic meridian. On the base line measure a convenient length (in links, feet or metres according to the divisions of the measure you use) with either a steel band measuring chain, an ordinary land chain (Fig. 7) or—failing these—metre or yard rods (put end to end) or tapes. Draw the plan on paper pinned on a drawing-board mounted on a camera-stand or supported by a strap over the shoulder. Properly made " plane tables " (Fig. 15) for such work may be obtained from opticians and scientific instrument makers. Decide carefully on a suitable scale before beginning. Obtain directions either by the sighting ruler suggested in Expt. 2 (*b*) above, or by more accurate apparatus.* Be careful that whenever a " sight " is being taken, the needle of the compass lies exactly over the *NS* line on the paper. Also place a pin at the point from which you sight and have the edge of the sight-rule against this pin when you sight. Draw each sight-line as soon as its direction has been obtained, and at once measure the length, either by tape or by careful pacing (having previously determined the average length of your stride by pacing a measured distance in the playground), and mark it to scale on the plan. As in the previous exercise, obtain the positions of some of the points by the intersection of sighting-lines; after a little practice this method will be found to give better results than pacing.

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* Accurate measurements of the angle between two distant objects can be made by using either :

(1) A prismatic compass—a combination of compass and sighting ruler sold by instrument makers.

(2) A sextant : a simplified form of sextant known as the *Anglemeter* is sold by Messrs. W. & J. George & Co., 157 Great Charles Street, Birmingham, for 2s. 9d.

(3) A theodolite : a *School Theodolite* giving excellent results may be obtained from Mr. W. B. Nicolson, 54 Hill Street, Garnethill, Glasgow, for 35s., or from Messrs. J. J. Griffin & Sons, Ltd., Kingsway, London.

(4) Serviceable instruments may be obtained from any of the better known optical firms in India, and for Government Colleges or other institutions from the Mathematical Instrument Office, 13 Wood Street, Calcutta.

4. A simple map. (*Outdoor work.*)—Select a suitably small area in your neighbourhood, preferably diversified in character and with numerous objects—*e.g.* trees, gates, corners of buildings, etc.—which can be used for sighting purposes. Measure a base line with a land chain (Fig. 7), and drive one of the arrows or a post (*e.g.* a cricket stump) vertically into the ground at each end of the base, putting the post at one end just *inside* the handle of the chain, and at the other just *outside.* Before beginning the drawing, decide on a scale which will allow the area to be included on the paper. From one end of the base, sight the other end, and observe the angle which its direction makes with the compass needle. This angle, which gives the compass bearing of the base line, is called the *azimuth* (p. 17) of the point sighted. An azimuth is always measured in a horizontal plane from the *NS* line and usually clockwise from the south end. Draw the base line to scale at this angle with the *NS* line on the paper, and in such a position that sufficient room will be left on all sides for the drawing. As before, be careful that the compass, laid on the paper, lies parallel to your *NS* line when a sight is being taken.

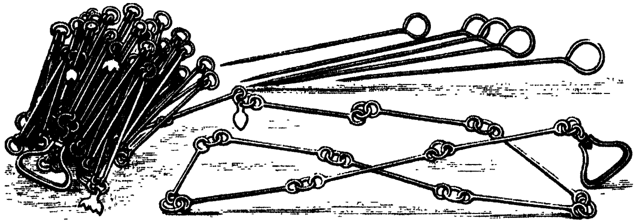

FIG. 7.—A surveyor's land chain and " arrows ".

It is obvious that any line, once represented accurately on the map, may be taken as a base for further observations, and that the positions and distances of inaccessible, but fairly near, objects may be obtained by the intersection of sighting-lines. Determine a few such distances; obtain, *e.g.* the width of a river by sighting an object from two points on the opposite bank.

When the positions of a large number of points have been obtained, the outlines of walls, streams, etc., may be drawn in by freehand. With dividers measure on the plan the length between any two points;

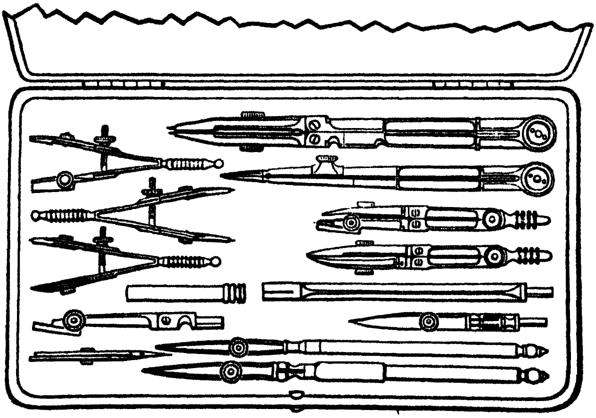

FIG. 8.—Drawing instruments used in preparing survey and engineering plans.

calculate from the scale the real distance to which this corresponds, and then test your result by pacing.

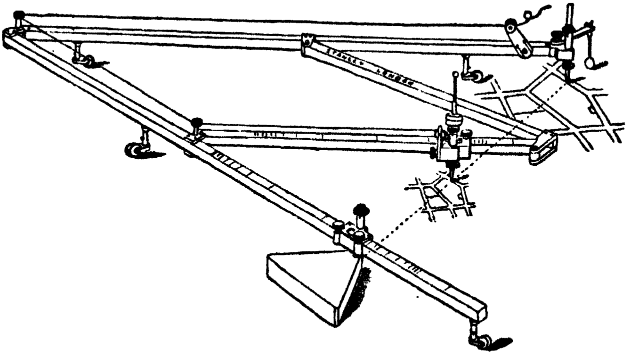

FIG. 9.—Pantograph or instrument used for copying drawings by enlarging or reducing them to any normal size.

5. Revenue survey maps.—It is possible to obtain a map of almost any village area in India. The Governments of the various Provinces, as the chief landowners of these regions, have revenue maps for administrative purposes. These revenue survey maps are of two main types: (*a*) Manzawar or malguzar maps, on a scale of 4 inches to the mile,

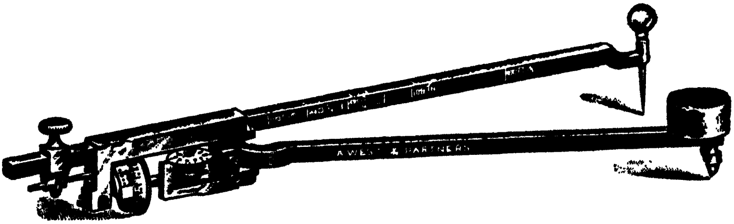

FIG. 10.—Planimeter used for measuring areas or maps or plans.

showing village boundaries, and (*b*) cadastral or patwari maps, on a scale of 16 inches to the mile, showing details of the village areas. Both

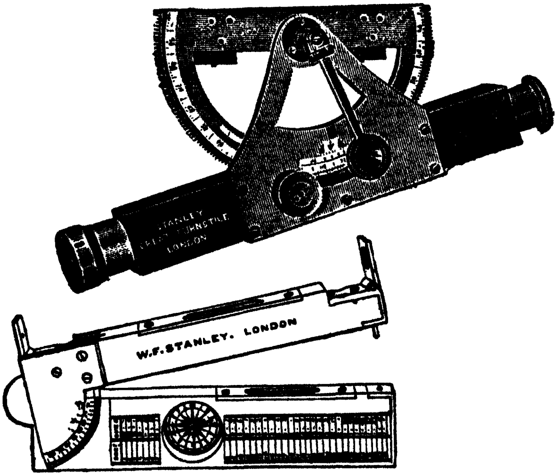

FIG. 11.—Abney level (upper) and sighting clinometer (lower). These instruments may be used for determining gradients, slopes and differences of level.

types of map will prove useful to the student for the study of his village lands—for ascertaining directions and distances between conspicuous objects or in checking the outlines and areas of fields.

6. Town and cantonment maps.—The Survey of India, Map Sales Office, 13 Wood Street, Calcutta, supply large scale guide maps and plans of several towns and cantonments in India. The Calcutta and Howrah guide map is on a scale of 3 inches to the mile ; that of Pachmarhi on a scale of 6 inches to the mile ; while the cantonment maps are generally on a scale of 64 inches to one mile. Obtain, if possible, the best available map of your neighbourhood and compare it with the map you have made. With dividers and a good scale measure the distances between several familiar points on the plan and calculate the real distances.

7. The one-inch (standard) map.—The Survey of India publish no maps equivalent to the standard six-inch maps of the Ordnance Survey of Great Britain. The best general or standard maps in India are the one inch to the mile sheets. Obtain the sheet covering your town or village and compare it with the guide or cantonment plan of the same area, noticing the difference in size of the representation of your neighbourhood. Take the map to the highest point accessible in the district (*e.g.* a hill or tower), and identify as many as possible of the features marked on it.

Do not, for the present, pay much attention to any heights marked on the plan and map, but, after finding your own position, observe carefully the direction and distance of each well-marked feature of the landscape. Estimate the distances, and check your estimates by reference to the map.

The broad principles of map-drawing.—Since a map is to represent in miniature a portion of the earth's surface, it must not only show the directions in which the various features of the landscape lie with regard to each other, but it must also display them in correct proportion as to size and shape. Let us suppose, as an illustration, that a rectangular field is 150 yards long and 100 yards wide, and that the two long sides, *AB* and *DC* (Fig. 12), run in a north-easterly direction. It would not be sufficient for a map of the field to show merely that *B* was to the *NE* of *A*, *C* to the *SE* of *B*, *A* to the *NW* of *D*, and so on ; for these facts might be true of a field having a quite different shape. The map must also show the proportionate length of the sides of the field ; that is, the sides *AB* and *CD* must each be shown as having 1½ times the length of *BC* or *DA*. The sides *AB* and *CD* might, for example, be drawn 1½″ long, and the sides

BC and *DA* each 1″ long. The drawing would in that case represent the field on a scale of one inch to 100 yards.

Fences or other lines at right angles are recognised fairly easily as such, and to draw them in plan is a matter of no great difficulty. For, when the direction of one line has been found by the compass, any other information necessary can be obtained readily by measurement with a tape or chain, or by pacing.

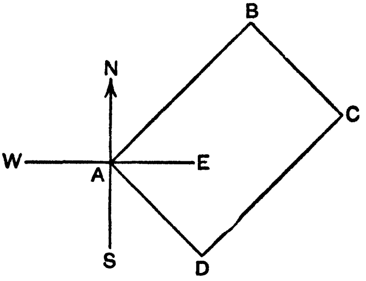

FIG 12.

In work on map-drawing from nature, however, lines meeting at unknown angles are always found, and the representation of these requires special care. Let us take as an instance a field enclosed by straight fences, and having the shape shown in Fig. 13. A plan or map of such a field is begun by marking, upon a sheet of paper pinned on a drawing-board, a dot in a convenient position to represent, say, the corner *D* of the field. Through this point is drawn a straight line, parallel to the side of the paper, to represent the magnetic meridian of the point. The upper end of the line is marked *N*, the lower end *S*. Next, the surveyor, standing at the corner *D* of the field, places a pocket compass on the paper so that its centre is over the line, and turns the drawing-board so that the needle itself lies along the meridian line *NS*. A "sighting-ruler" or alidade is now laid carefully along the paper, with its edge against a pin in the paper at the position of *D*, and turned to point in the direction first of *C* and then of *A*, and a straight line is drawn to represent each. The angles *NDC* and *NDA* are in this case magnetic bearings but, measured in a land where the compass has practically no error, they are called the **azimuths** of the points *C* and *A* with respect to *D*.

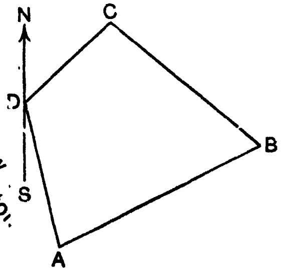

FIG. 13.

Strictly speaking, all azimuths are measured clockwise from the south. The lengths of the fences are ascertained by pacing, and are

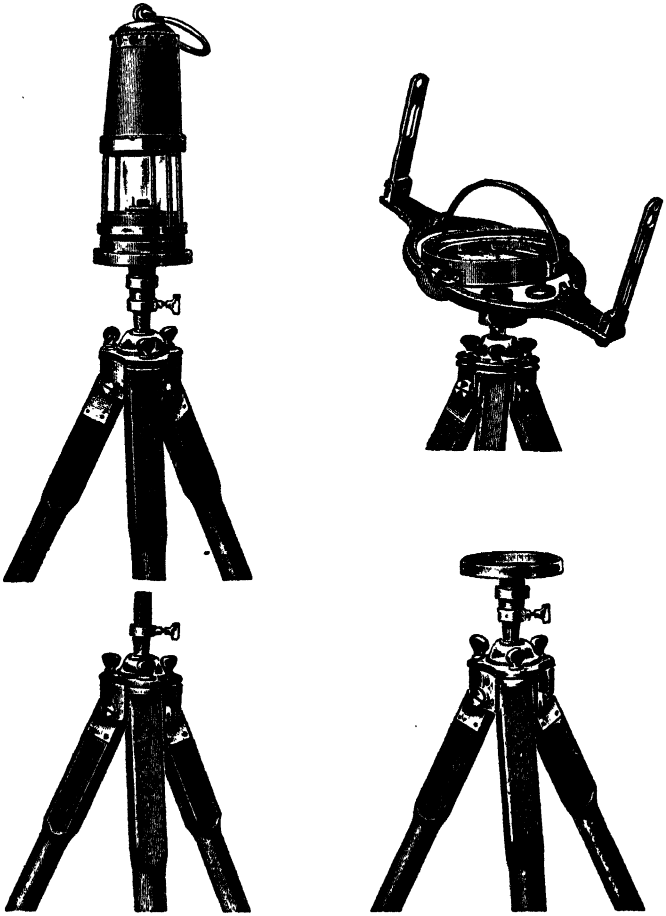

FIG. 14.—A miner's dial or compass, with extra stands, lamp cup and lamp. These instruments, with a measuring chain, are used in making traverse surveys in mines. They could be equally well used for making traverse surveys at night.

marked on the lines to some convenient scale. The points *C* and *A* are thus obtained. The remaining point *B* may be determined in a similar manner from either *C* or *A*, the length of the fence being measured by pacing as before. By drawing *NS* lines through each point that is fixed on the map by sighting and pacing, a survey can be gradually carried outwards along a very irregular line and, after a circuitous traverse, return to its starting point. Such a survey is known as a **traverse survey** and may or may not close on its starting point, but it must close on a known point so as to check its accuracy. Such traverses are useful in railway or boundary surveys in open plains or in forest country where triangulation methods are difficult. Where the country has conspicuous landmarks the positions of distant points are best determined by the intersection of sighting-lines drawn from the ends of a carefully measured base. Fig. 14 illustrates a miners dial or surveying compass, with spare stands for front and back stations, miner's safety lamp and lamp cup. These instruments are used in all mines for making underground traverse surveys, and could be quite well used for night work on the land where a traverse along a road, track or jungle path was to be carried out urgently.

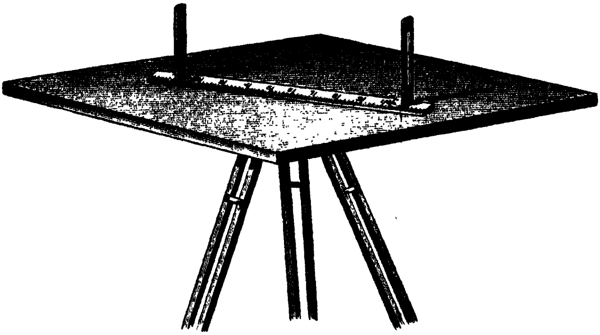

FIG. 15.—Sight-rule on plane table.

Such survey work is facilitated by having the drawing-board—technically known as a *plane table* (Fig. 15)—mounted on a tripod stand, or suspended by a strap from the shoulders. In the latter case two students may with advantage work together : one ensuring that the *NS* line is kept parallel to the compass needle, whilst the other ascertains the directions of distant objects by "sighting" along the surface of the board. To aid in correct sighting, it is useful to fix an ordinary pin at the point on the paper which represents the position of the observer, and to use a second pin to mark a point exactly between the first and the sighted object. It is better to use a proper *sighting-ruler* or alidade (Fig. 15), or prismatic compass (a combination of sighting-ruler and compass); simple substitutes are described on pp. 11 and 12.

An object may be sighted from each end of a carefully measured base line in this way, and the intersection of the two sighting-lines will give the position of the object on the plan. Its distance may now be calculated by trigonometry, or found by measuring the line on the plan and multiplying by the necessary factor chosen for the scale: *e.g.* 1200 if 100 feet is represented by one inch on the plan or map. The scale thus gives the factor or representative fraction $\frac{1}{1200}$. Actual measurement along the ground to the intersected points is thus unnecessary if the observations have been made carefully. The length of each new side of a triangle made by intersected sights is thus obtained, and each may now be used as a new base line, and further observations made. The features between the points are then carefully filled in, and a complete map of the surface features of the district is thus obtained.

This—the method of **triangulation** (Fig. 33)—is essentially the principle upon which maps of a country are actually drawn, although in accurate work great refinements are necessary at every stage—in finding the meridian, and in measuring both the base line and all angles. It is thus evident that a base line is the foundation of a triangulation survey, and must be measured with the utmost care. In the Great Indian Triangulation the base line near Dehra Dun, which is 7·42 miles long, was found to be only 2·396 inches in error when re-measured. Its calculated length, as the side of a triangle, on a triangulation survey carried north for 260 miles from another base line near Sironj, was only 7 inches in error.

The excellent maps published by the Survey of India, of which Figs. 26 and 29 are samples, are examples of the best work of this kind: and the student is recommended to study very carefully all the published maps showing his own district, comparing them whenever possible with the actual features of the landscape. The standard one-inch to the mile topographical maps (Fig. 29) are prepared from plane-table surveys on a trigonometrical basis. The surveyor goes over the ground with his plane table, which he sets up at a sufficient number of points to enable him to " cut " in all the prominent objects and to sketch the general features of the country. The plane-tabler actually goes over only a comparatively small portion of the ground, the greater part being sketched from his plane-table stations.

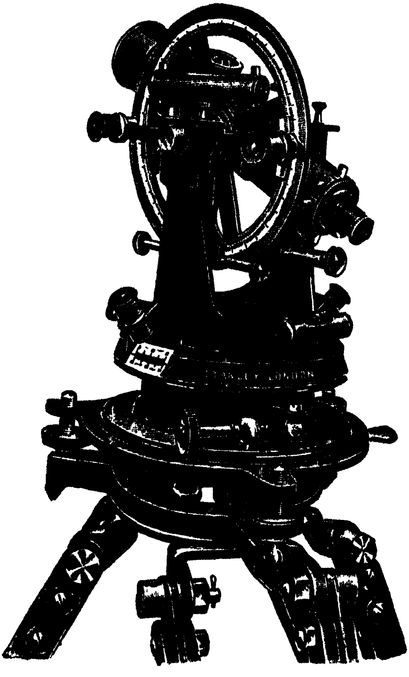

FIG. 16.—Tacheometer-theodolite with hollow axis to permit vertical sights being taken downward into a mine shaft.

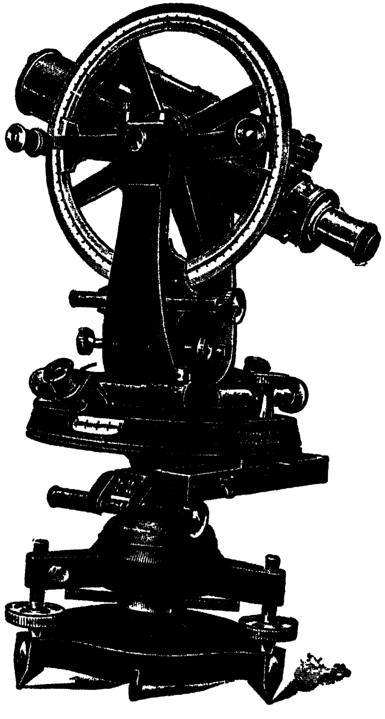

FIG. 17.—Normal transit theodolite for the triangulation surveys of estates and mineral properties or traverse surveys along railways.

EXERCISES ON CHAPTER I

1. Mention the essential parts of a plane table, and the use of each. Describe how you would, by its means, make a map of the hall in which you are seated.

2. A boy wishes to make a plan of the cricket field at his school, showing the position of the pitch. He has a mariner's compass and a tape measure. The field is level. Describe fully how he may proceed.

3. How would you proceed to prepare a plan of a four-sided (but not rectangular) field with a chain or tape measure, but without any instrument for measuring angles?

4. Describe two methods by which you could lay down a line running east and west through a given point on the earth's surface.

5. Explain any method by which you could draw a map of a small, level district (such as a park or recreation ground) with some degree of accuracy.

6. Define altitude * and azimuth. What is meant by the statement that a certain point has altitude 15° and azimuth N. 135° W.? How is a compass card divided? How would azimuth N. 135° W. be expressed in terms of the compass?

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* See p. 43.

CHAPTER II

THE MEANING OF A MAP (*Continued*)

3. SURFACE RELIEF

1. Comparative height. (*Outdoor work.*)—Walk over the local area you have mapped previously and try to discover which of the points shown is highest, which lowest, etc. Mark the lowest point *a* on the map, the next higher *b* and so on. When there is any doubt as to the comparative heights of two points, look from one to the other along the surface of water in a tumbler or, better, in a U-tube or water-level (Fig. 18). If the slope of the ground is too gentle for even this to be of use, notice which way the water flows in rainy weather. Observe the direction of the flow by means of a compass, and indicate its direction in as many places as possible on the map.

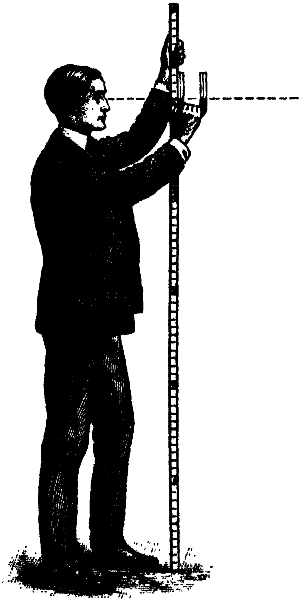


FIG. 18.—A simple water-level and levelling staff used for measuring relative heights.

2. The measurement of height. (*Outdoor work.*)—Take either a levelling staff, or a six-foot wooden rod graduated in inches (Figs. 18 and 19), to the lowest point shown on your map. Carefully holding the rod vertical, observe the height at which the water-level (tumbler or U-tube) must be held so as to be on the same level as the point next higher (*b*). Mark this height on the map. In the same way find how much higher *c* is than *b* and note it on the map. Do the same with all the other points.

3. The modelling of surface relief.—Copy your map on cardboard, and at each point of which you know the relative height push—up to its head—a slender pin vertically through the cardboard from below. Decide on a suitable scale of heights, say 10 feet to one inch. Cut each pin to the proportional height with a wire-cutter, and then make a model of the area in wet sand, modelling clay or plasticine, using the pins as guides. If the heights of the model appear exaggerated, cut the pins down to a smaller scale and repeat the exercise until the heights seem reasonably represented. Compare the vertical and horizontal scales. If convenient, take a photograph of your model, with the light falling on it from one side.

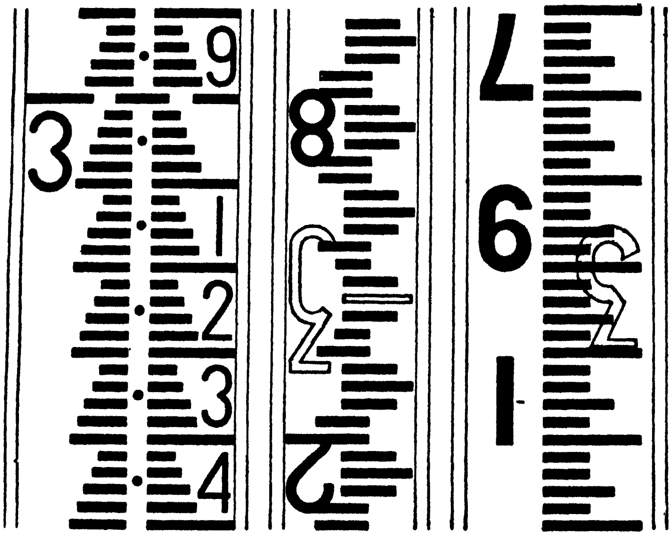


FIG. 19.—Three types of graduations on levelling staffs. The pattern on the left is suitable for a staff used with a normal water-level (Fig. 20). The other two with inverted figures are used with levels having telescopes (Fig. 21) and with tacheometer theodolites (Fig. 16).

4. The measurement of slope.—(*a*) *A clinometer.*—Make a protractor in cardboard, but in numbering the scale take the usual position of 90° as zero. Prick a hole through the centre point and pass through it, and secure, by a knot, a piece of thread the other end of which carries a small weight (*e.g.* a leather button). Gum the protractor accurately along one edge of a school slate or other rectangular frame, as shown in Fig. 23. This is a simple form of clinometer. More elaborate forms of clinometer, such as the Abney level and the sighting clinometer, are shown in Fig. 11.

(*b*) *Outdoor work.*—Measure the slope of the ground in various steep places by holding your clinometer in a vertical plane with the base line parallel to or on the ground and reading the position of the thread on the scale. A slope of 1° corresponds to a rise or fall of 1 in 57·3, *i.e.* 1 foot in about 19 yards. How does your scale-reading, thus interpreted, agree with the heights shown on your map ? Write on your map, along the directions of slope previously obtained by observing the flow of water, the approximate gradients, *e.g.* 1 in 19, 1 in 11, etc.

5. Gradients of roads. (*Outdoor work.*)—Estimate the gradients of any sloping roads in your neighbourhood, first mentally and then by using both the angular measurement with the clinometer and then the water-level and levelling-staff method. In pacing distances count your steps both up and down the slope and take the mean. Do you find you have a tendency to exaggerate the gradient mentally? It is said that " heavy waggons cannot go up a slope steeper than 8° without extra horses ". If possible, find whether this statement holds good for your district.

6. Slope expressed by shading.—Shade a copy of your map, very lightly on slight slopes and to varying degrees of darkness, according to the steepness of the ground. Leave all the flat (*i.e.* horizontal) ground unshaded. Compare the shaded map with the photograph of the model, if one was obtained.

In his " Text-Book of Topographical and Geographical Surveying ", Sir Charles Close has defined **Surveying** as the process of accurately determining and recording the relative positions and features of the earth's surface, and **Topography** as the delineation of the natural and artificial features of a locality. Topographical surveying is, therefore, the process of accurately determining and recording the relative positions of the surface features of the earth, and of delineating them on a map. The surface features are of two kinds : **natural,** such as rivers, lakes, forests, hills, and the undulations of the ground ; and **artificial,** that is to say, those produced by the agency of man, such as towns, railways, roads and canals. A topographical map should depict all the surface features which can be legibly drawn; it should show all the accidents of the surface which distinguish it from a level, featureless plain. The amount of information presented on a topographical map is thus conditioned by two principal factors, the complexity of the surface features and the scale of the map.

The surface relief of the land.—A map showing merely the distances and directions between the various points indicated—as if all these points lay on a perfectly flat surface—gives, in most cases, a very inadequate idea of the real nature or topography of the district. The sculpturing of the surface into more or less pronounced hills and dales is, as we shall see later, of the deepest significance, and it is necessary that such surface-relief should be recorded on maps. This might be done, roughly, by conventional signs showing which point was lowest, which was next in height, and so on. In a student's sketch map the lowest point shown might be marked *a*, the next higher point *b*, the next *c*, for example.

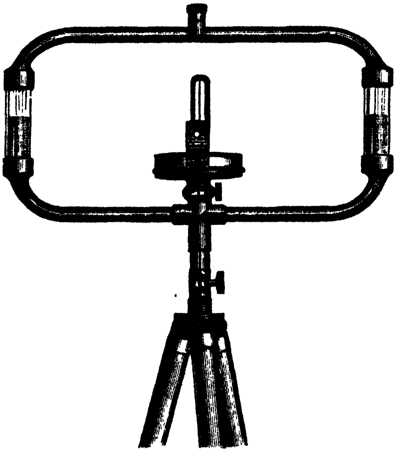


FIG. 20.—Water-level with prismatic compass.

Such a comparison of heights is made easily by looking along any horizontal surface from one point to another. A simple and convenient means of obtaining a horizontal surface is a fairly large U-tube, such as is used in laboratories. Water is poured into the tube and, of course, stands at the same horizontal level in both limbs. Holding the tube so that he looks along the surface of *both* columns of water, an observer sees at once whether any distant object is higher or lower than his eye. As a simpler form of "water-level", water in a tumbler may be used in the same manner, but it is not so easily carried in the field, and has the further disadvantage of not affording so extended a horizontal surface. In small areas for rapid level observations a water-level like that shown in Fig. 20 is often employed. It has the advantage of enabling one to read azimuth angles to the various points at which the levelling staff is held. Over ground which is too flat to be tested conveniently in this way, or of which the slope is imperceptible to the eye, the direction of flow of rain water plainly shows on which side the higher land lies. Indeed, whatever the extent of the slope, its direction may be discovered easily by the flow of water and, after comparison with the compass, may be indicated on the map.

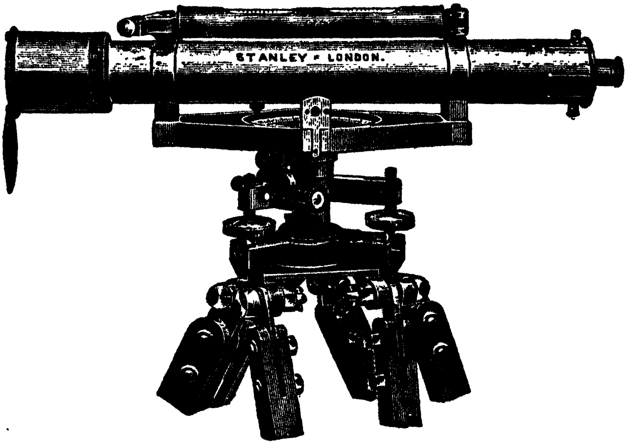


FIG. 21.—Typical surveyor's level, fitted with telescope for sighting, bubble tube (on top) and magnetic compass (below), and mounted on stand for field use.

The measurement of relative heights.—With the help of levelling staves or other graduated rods (Fig. 18), it is easy to extend the use of a water-level to the measurement of the extent by which one point is higher than another. Taking up his position at the lowest point, the student arranges his water-level alongside the vertical staff at any convenient height (say 5 feet), which is noted, and looks along the level to another graduated staff held vertically by an assistant at the next higher point *b*. If the water-level is seen to be at the same height as the 2 feet mark on the staff at *b*, the point *b* is evidently 3 feet higher than the point *a*. From *b* an observation of the height of *c* over *b* is next taken, and the process is repeated from point to point until all the relative heights are known.

In official surveying, say, along a road or a railway line, the *level* usually consists of a telescope provided with a spirit level and mounted on levelling screws on a tripod (Fig. 21). The instrument is placed between two staves, one of which is further up and the other further down the slope. The reading of the level on each staff is taken in turn, the difference being the difference in height of the ground between the staves. The level and the back staff are then moved in front of the front staff, which is kept in the meantime in the same position, and another pair of readings is taken. The process may be repeated for miles. In 1880-81, the tidal stations at Madras and Bombay were connected for the first time by a line of spirit levels carried directly across India—over a line 730 miles, chiefly along the railway—and it was found that the mean sea level at Madras was 3 feet higher than that at Bombay. This 3 feet is possibly due partly to errors in levelling, and partly to variations in the crustal density of the earth, as will be explained later (p. 94).

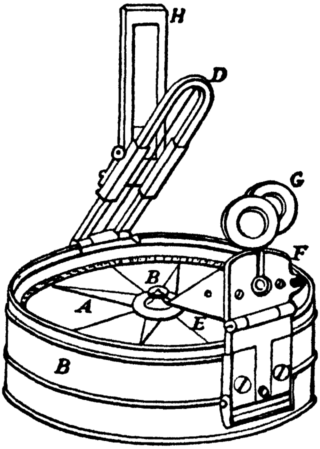


FIG. 22.—Sketch of a prismatic compass, showing prism attachment at *E*, peep sight at F, front sight at *D*, compass at *A* and dial cord at *B* inside the metal case *B*. *H* is a mirror and *G* are lenses for reading the graduations on the dial through the peep hole *F*.

The measurement of slope.—Knowing both the distance and the difference in height between two points, it is easy to calculate the average slope, or gradient, from one point to the other. A gradient of 1 in 57·3, that is, 1 foot in 19·1 yards, corresponds to a slope of 1 degree. The student will find it instructive to determine the gradient of the steepest roads or paths in the district, and to notice how much smaller, in general, is the inclination than the untrained eye would have estimated it to be. As a result of experience the gradients of all roads are made as small as possible. This is specially the case with much-used roads.

A rough idea of the angle which a steep path makes with the horizontal may be obtained by so holding a protractor (mounted as in Fig. 23)—from the " centre point " of which hangs a weighted thread (plumb line)—that while its plane is vertical the base line is parallel to or actually on the ground. For rapid and accurate determinations of slopes of more than 5° an instrument called a **clinometer,** constructed essentially on the same principle, but provided with a means of " sighting " along the base line, is used. A simple form of home-made slate-clinometer is shown in Fig. 23.

The modelling of surface relief.—When the relative heights of the points marked in the student's map have been measured in the manner described, they may with great advantage be represented to scale by a model in clay, or plasticine, built up on a sheet of cardboard. Unless the district be very hilly it will as a rule be found necessary to employ a larger vertical scale than the horizontal scale, in order to obtain a realistic effect . This fact illustrates the tendency of most people to exaggerate mentally the heights of elevated parts of the scenery, a tendency which it is well to bear in mind.

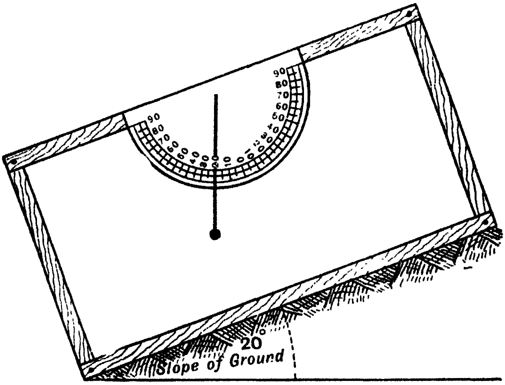
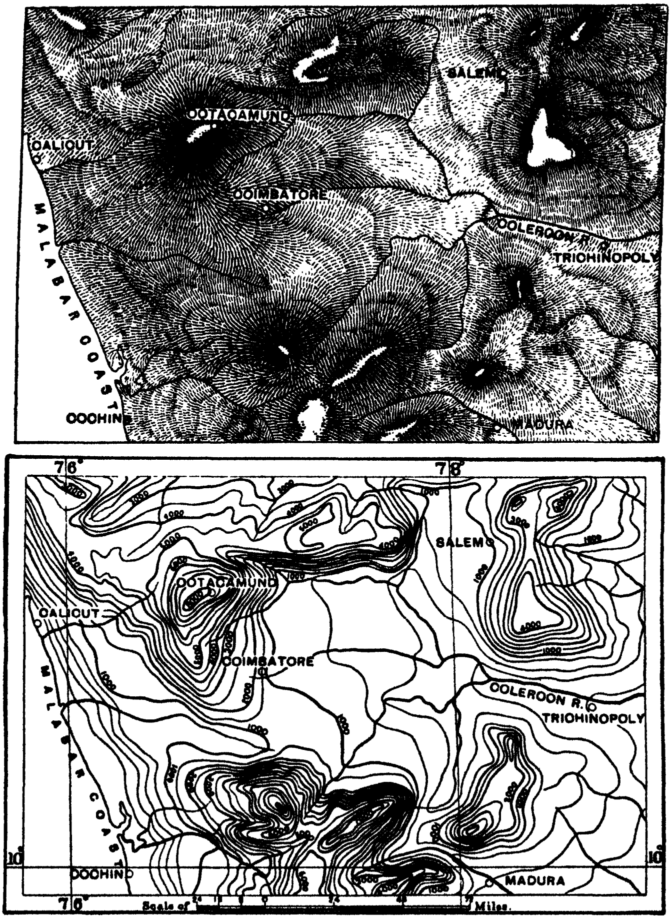


FIG. 23.—A simple slate-clinometer.

Hachures and hill shading.—A carefully constructed model of this kind may be taken as a guide in an attempt to represent, by shading a flat map of the same district, the " ups and downs " of the surface. In such work it is usual to leave flat parts unshaded, and to graduate the depth of shading according to the steepness of the slope. In Fig. 24 the top map is shaded in this manner. The details of the shading, however, have a further significance, for the lines employed—called

hachures—are not only thickest and closest together where the slope is greatest, but they are drawn in the *direction* of the slope, and so



Note The Contours below 1000 ft have been calculated at 200 ft apart taking the Coast line at 0 and those above at intervals of 500 ft

FIG. 24.—Hachured and contoured maps. The Palghat Gap lies *SW* of Coimbatore.

represent also the general direction in which water would flow over the surface if free to choose its own path. The chief advantage of hachured maps is that they convey, at the first glance, a general idea of relative steepness. A drawback to their use is that the hachure lines often interfere with the legibility of the lettering and may also obscure other details. In the modern one-inch Survey of India maps, hachures are replaced by colour shading to obviate this difficulty. The shading is supposed to represent the shadows of a relief map or model when illuminated from a north-westerly direction. Some slopes are then lighted and others in shadow and it requires considerably more skill to shadow tint a map than to put on hachure lines.

4. CONTOURS

1. A plasticine model.—In the bottom of an ordinary wash-basin make in plasticine a model of a more or less imaginary landscape—including a mountain with two peaks of different heights, smaller hills, and a few valleys running into one main valley. Let the lowest part of the model be at one side and about $\frac{3}{4}$ of an inch from the bottom of the basin, and let the summit of the highest peak be a little below the level of the rim. Stick a graduated ruler vertically into the plasticine at the lowest part of the model.

Having placed the basin in a suitable position, hold a fine-rosed watering-can over it until water has collected in the basin up to the level of the first inch mark of the ruler. Suppose this to be sea level. Make a careful drawing—natural size—of the outline of the edge of the water (the shore line). Now add water from the can as before, holding it well up, so that the " rain " will be as fine as possible. Observe carefully how it flows off the heights in various directions, how the small streams unite to form rivers in the valleys, how these join to form a larger river which discharges into the sea. Continue watering until the level has risen to the second inch mark on the ruler. Now make a drawing of the edge of the water on the same paper as before, measuring if necessary with blackboard compasses from the ruler or from marks on the rim of the basin. Mark this outline " 100 feet contour ".

Continue the process until the highest peak alone is left as an island above the water, stopping to draw the contour lines as the water reaches each successive inch mark, and numbering each line in hundreds of feet as soon as drawn. What is the general shape of a contour in a narrowing valley? In what directions are the contours crossed by rivers (*a*) in narrowing valleys, (*b*) elsewhere?

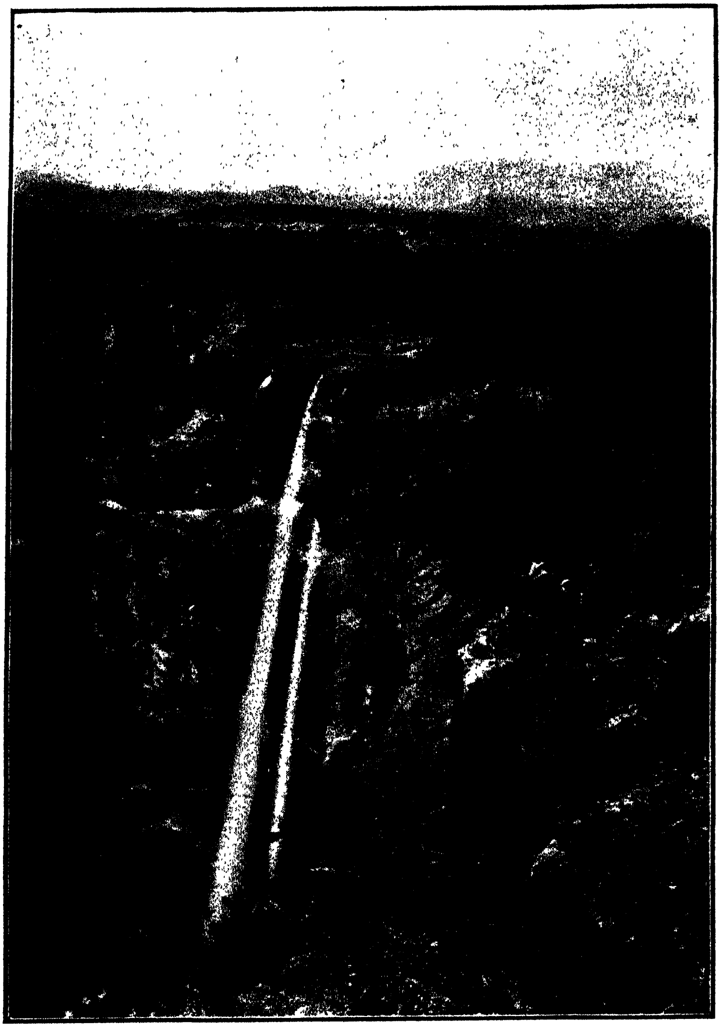


FIG. 25.—The Falls of Mawsmai, 1,150 feet, at Cherrapunji, Assam. The Cherrapunji plateau is seen above the falls. (With the permission of the Director, Geological Survey of India. Photo by C. S. Fox.)

Finally, add water to the top of the peak, read its height on the ruler, and note it on the map. Now siphon off the water ; one or more pools (lakes) may be left in the valleys. Carefully compare your contoured map with the model itself. Notice that where the slope is steepest the contours are nearest each other ; where the slope is gentle they are far apart.

2. Hachures.—Copy the map of your model landscape (Expt. 1) on a smaller scale, and shade it by hachures (p. 30). Remember that hachure lines are in the direction of the slope, *i.e.* in which water would flow, and that this direction is in most cases at right angles to the neighbouring contour line (Expt. 1). Draw the hachures thickest and closest together where the slope is greatest, *i.e.* where the contours are closest.

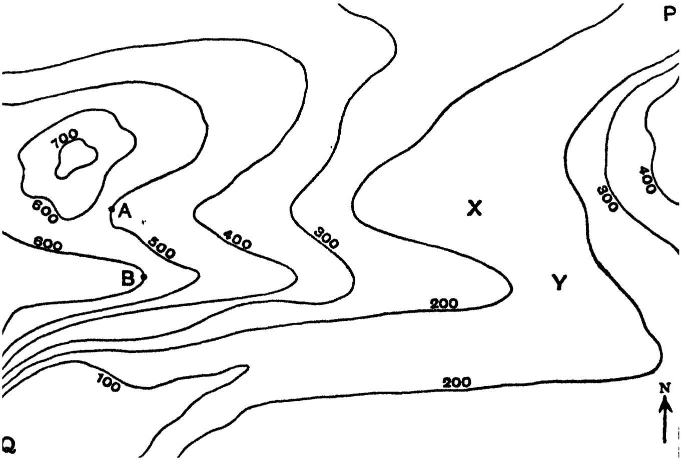


FIG. 27.—Map to illustrate Expt. 3, Section **4**.

3. General exercises on contours.—(*a*) In Fig. 27 the contours are marked in feet and the scale is one inch to a mile. Suppose yourself to be walking for 1½ miles due east from *A* ; how does the ground slope (i) behind, (ii) in front, (iii) on your left, (iv) on your right? What name would describe the character of the surface between *A* and *X*?

Answer similar questions with respect to a walk from *B* to *Y*.

In what directions would water falling at *A* and *B* respectively flow?

Imagine yourself to be walking from *P* to *Q* along the lowest ground you can find ; what is the approximate length of the route? Briefly describe the view to be seen at intervals of a mile.

Where is the steepest ground shown on the map?

Copy the map and shade it by hachures.

(*b*) Represent by numbered contours (i) a deep valley with a slope of 50 feet per mile ; (ii) a shallow valley with a similar slope ; (iii) a hill 75 feet high with a slope of 60 feet to the mile on the north side and 40 feet to the mile on the south (10 feet contours) ; (iv) a pass running north-east, at a height of 1200 feet, between two peaks 1650 and 1400 feet high respectively.

4. Contoured map of the neighbourhood. (*Outdoor work.*)—Take your stand at the lowest point of the area you have previously surveyed, and, sighting with the water-level at a height of 5 feet, signal to a companion where to place small wooden pegs, or otherwise to mark points, at this level. Obtain the positions of these points on your map in the usual manner, and through them draw the 5 feet contour line (considering the lowest point as zero). Next obtain the 10 feet contour by working similarly from a point on the 5 feet line, and continue until the highest point is reached. Where the ground is irregular the marked points should be placed closer together.

5. Cardboard model of neighbourhood.—Duplicate your contoured map so as to have at least as many copies as the number of contours shown. Paste one map on cardboard ; cut out from a second map the area enclosed by the 5 feet contour line, from a third that enclosed by the 10 feet line, and so on with each contour. Then paste each on a separate piece of cardboard, and cut the cardboard to the outline with a sharp penknife or a fret-saw. Build up the model by gumming the contour segments in position on the complete map. When the gum is dry the " terraces " of the model may be smoothed off, if desired, with putty or plasticine.

(*b*) Repeat the exercise, using one-inch Survey of India maps of your district if the slope is very gentle. These maps can be bought from the Survey of India, Map Sales Office, 13 Wood Street, Calcutta. Mount one or two maps of the district with the aid of thin glue on cardboard about one-twentieth of an inch thick. For a hilly district large scale contoured maps should be used.* With a fret-saw cut through the even hundred contour lines of one map and through the odd hundred contour lines of a second map. Thus obtain pieces of cardboard or fretwork, which can be glued one above the other to build up a relief map of the district. The chief features of the map can be accentuated on the model.

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* In addition to the Town Guide Maps, Cantonment Plans and Revenue Survey Maps already mentioned on p. 14, there are Forest Maps of the Government Reserve Forest areas on scales of 8, 4, 3 and 2 inches to the mile. These maps can be procured from the Forest Map Office, Dehra Dun, United Provinces.

6. Aneroid barometer. (*Outdoor work.*)—Procure an aneroid barometer (Fig. 36); read the dial at the bottom of the highest accessible building and then immediately take it to the top of the building, tap it *gently*, and notice to what extent the position of the index has changed.

Contours.—Although hachured shading (p. 30) gives a very effective representation of the general steepness and direction of slope of the land, it does not afford any information respecting actual heights. These and many other features are best shown by what are called contours. A **contour** is defined as " the representation on a map of an imaginary line joining all immediately adjacent points which are the same height above mean sea level ".*

Thus a line on a map, joining all adjacent points at a height of 100 feet above mean sea level, is called the 100 feet contour. We may imagine it to show where the shore line would be if the sea were to rise 100 feet above its present normal level. On steeply sloping land the new shore line would not be far—as seen from above—from the present position of the edge of the water; but on a gentle slope a height of 100 feet would only be reached at a considerable distance from the present shore. Similarly, if the sea were to rise still another 100 feet, the edge of the water (the line of the 200 feet contour) would be at a distance from the 100 feet line which would depend upon the steepness of the land between them.

Some typical contour-patterns.—Exercising the imagination in this manner, it is easy to form, from a contoured map, a mental picture of the configuration of the ground. Some of the chief patterns of contour lines are shown in Fig. 29, (facing p. 36) which is part of the one-inch to the mile sheet No. 52 D/2 and is an example of a hilly region. Fig. 26 (facing p. 32) is part of the quarter-inch, or 4 miles to the inch, map of Degree sheet No. 78 O, and shows plateau country adjacent to marshy plains. Both these maps are worth careful study. The contours are marked at vertical intervals of 100 feet up to a height of over 7000 feet in the former, while in the latter they are at intervals of 250 feet. In Fig. 29 (opposite) it will be noticed that within ¼ mile the land rises from 3085 feet (the height of the town, at the *C* of *Chamba*) to a height of 4335 feet—a slope of nearly 5000 feet per mile. Ground as steep as this is at

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* Sir Charles Close's " Text Book of Topographical and Geographical Surveying " (His Majesty's Stationery Office), 15s.

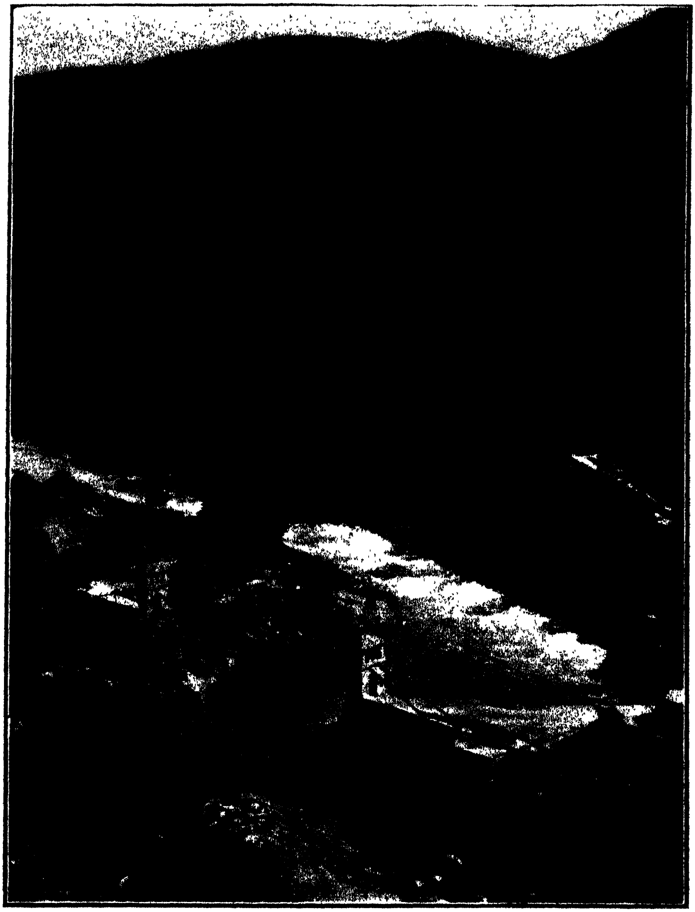


FIG. 28.—View up the Ravi, south-westward, from the cliffs of Chamba town overlooking the suspension bridge. Chatren peak, 7413 feet, is seen in the distance. (With the permission of the Director, Geological Survey of India. Photo by C. S. Fox).

Shah Madar is a cliff, but is often called a **crag**. The mountain of Chatren, 7413 feet, roughly 3½ miles to the south-south-west of Chamba, is the point of a **ridge** and not an isolated mountain culminating in a **peak**. No real peak occurs on the map (Fig. 29), but the ridge which trends south-east from Shah Madar to the trigonometrical station 6134 continues for another mile to a true peak at a height of 7578 feet. All the hills seen in the one-inch map (Fig. 29) are really **spurs** or **ridges** from higher points. The river in the valley is the Ravi, which flows north-westwards from Chamba. The town of Chamba is built on an old river **terrace**. Similar terraces occur further down the valley and also on the opposite side of the valley south of Chamba town. Fig. 28 is a view from the top of the Chamba terrace, looking south-westward over the bend of the Ravi at the iron suspension bridge. The river is seen at the foot of the terrace on which the village of Mangla is situated. Beyond it is the peak of Dharmari, 5968 feet, on a spur from Chatren. This point, 7413 feet, is also visible. The town would be under direct fire if guns placed on Chatren were to bombard the town of Chamba.

Fig. 26 (facing p. 32) shows the country around Cherrapunji plateau —4454 feet at Rangsanobo station to 5451 feet at Laitryngew point. As the slope continues up by Sohrarim to Dympep trigonometrical station, 6382 feet, it can be argued that Cherrapunji is not a true plateau. To the east are the deep **valleys** of the Umrew and Umstew, which **converge** and debouch at the gorge above Therriaghat barely 200 feet above sea level. To the south are the plains of Sylhet, covered with marshes and bhils even in the dry months and almost an inland sea of fresh water in the rainy season. To the west is the deep valley of the Umian, with its converging valleys and glens and its debouch just west of Shella at the level of the plains of Sylhet. The path from Shella to Cherrapunji crosses the **saddle** between point 3268 feet and the **escarpment** of Mawmluh 4400 feet roughly. The aerial ropeway from Cherrapunji to Bholaganj goes through a **gap** east of the **pass** up which the path from Bairang Bazar leads to Mawsmai. Under the aerial ropeway there is a stream which disappears underground in the limestone rocks, and there are " swallow-holes " and solution **caves** in the same rocks near Mawsmai. The escarpment east of Mawsmai is a true **precipice**, over which the stream from Cherrapunji drops in a sheer fall of 1150 feet. These falls of Mawsmai must be among the highest in the world, though the flow of water is trifling except after heavy rain or during the wet monsoon period when the scene (Fig. 25) is awe-inspiring.

Fig. 31 (opposite) is part of the Afghanistan sheet of the Southern Asia series, on a scale of $\frac{1}{2000000}$ or nearly 32 miles to one inch. It shows the region of the famous Khyber Pass between Jamrud in the North-West Frontier Province and Loe Dakka in Afghan territory. It is still true to say that the Khyber Pass is the main trade route from India to Central Asia.

Fig. 39 is a view looking east from the Khyber through a gap towards the plains of Peshawar.

Fig. 30 is a view looking westward over the bloody gorge of Ali Masjid into the upper valley, or col, of the Khyber river and towards the watershed at Landi Kotal. The Kabul river breaks through the hills in a great loop and emerges at Michni, where it spills in a valley delta where the drainage from north and south converges on it. East of Peshawar the river as a single stream discharges into the Indus. The Indus itself breaks through the hilly country at Kalabagh, where it spreads its silt below the gorge on the plains on Mianwali (Fig. 117).

Without referring to the one-inch map of Chamba, the student should draw a sketch map showing contours embodying all the facts given in the description. It will be easy, by comparing the completed sketch with the map, to see how far he has understood the map itself.

In the drawing of a contoured map from a given description of the topography of a district, the relative positions of the features mentioned should be first sketched lightly on the scale given. Any heights furnished should be marked next, and the contours put in last of all. In the contouring the most important facts to be remembered are:

(1) Contours are close together on steep ground, as on cliffs and crags, but are far apart on gently sloping ground.

(2) The contours both of isolated peaks and of depressions surrounded on all sides by higher ground are concentric curves, the heights increasing towards the centre in the former and decreasing in the latter case. Isolated depressions are rare except when filled with water, when they form lakes.

(3) Both valleys and sloping ridges are indicated by V-shaped contours. In the former case the angles of the Vs point towards the higher ground; in the latter they point to the lower ground. The angles are greatest in the most rapidly narrowing valleys, and least

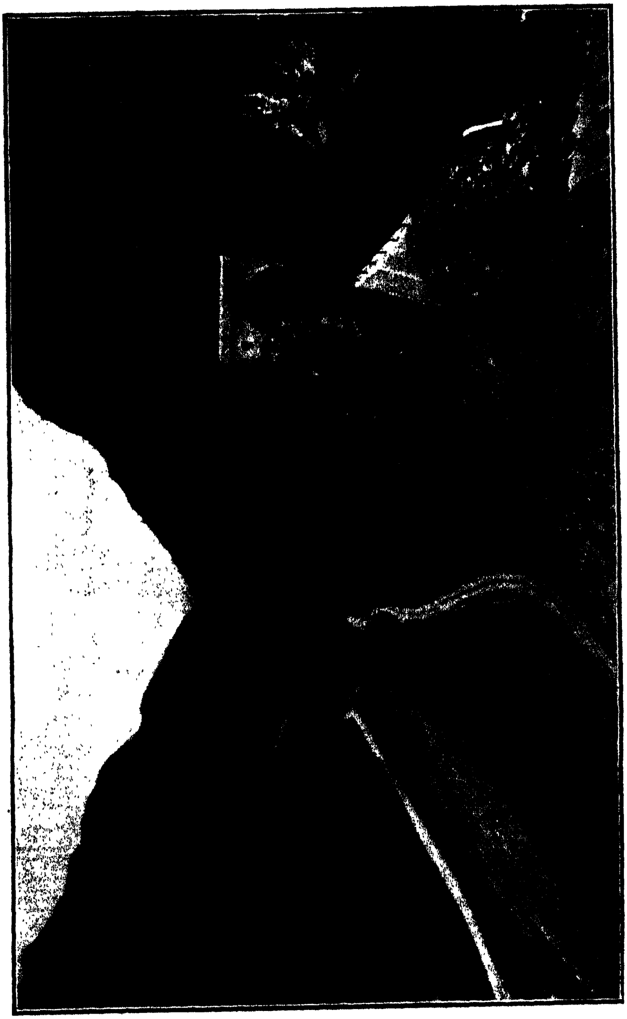


FIG. 30.—The Ali Masjid gorge, Khyber Pass, showing both military roads and the railway, at a tunnel, from Jamrud to Landi Khana. (With the kind permission of Messrs. Holmes of Peshawar.)

where the sides are most nearly parallel. The angles are closer together in steep valleys than in valleys with gently sloping beds.

(4) Rivers flow only in valleys, connecting the angles of the Vs.

Methods of contouring in the field.—It is a comparatively easy matter to find a number of points on the same horizontal level and, after marking the positions of such points on a map (in the manner described in Chapter I), to draw a contour line passing through them. **In making ordinary sketch maps** the water-level and levelling staff (Fig. 18) would be employed for this purpose, the observer signalling to an assistant at a little distance where to place a conspicuous mark. The observer would then move to the marked station and fix a third point in a similar manner. By continuing the process, points sufficient in number to fix the contour line correctly would be marked. In very accurate work more refined instruments on the same principle are, of course, employed.

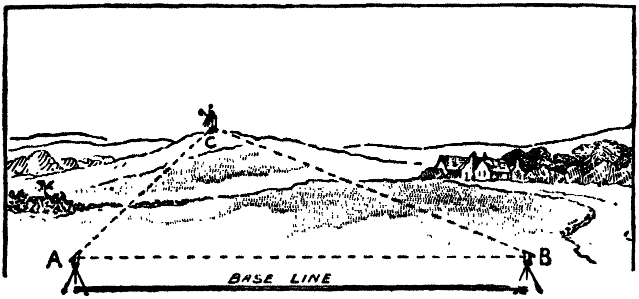


FIG. 32.—Surveying from a base line.

In a student's sketch map the first contour might conveniently be drawn in this way through all points five feet above the lowest level on the map, which might be regarded as of zero height, and succeeding contours might be found by working similarly from a point on the first contour.

In English **ordnance surveys**, however, the assumed mean level of the sea at Liverpool—known as the **Ordnance Datum** (O.D.)—is taken as zero level and is the plane of reference. The Survey of India has found that the best plane of reference is below mean sea level at Karachi, and is officially called the " Indian Spring low-water mark ". Even this datum, which differs from the Admiralty datum, is not entirely satisfactory. It is, however, the datum of Indian levelling operations, and the bench marks and contours of Indian surveys have been fixed or reduced to this datum.

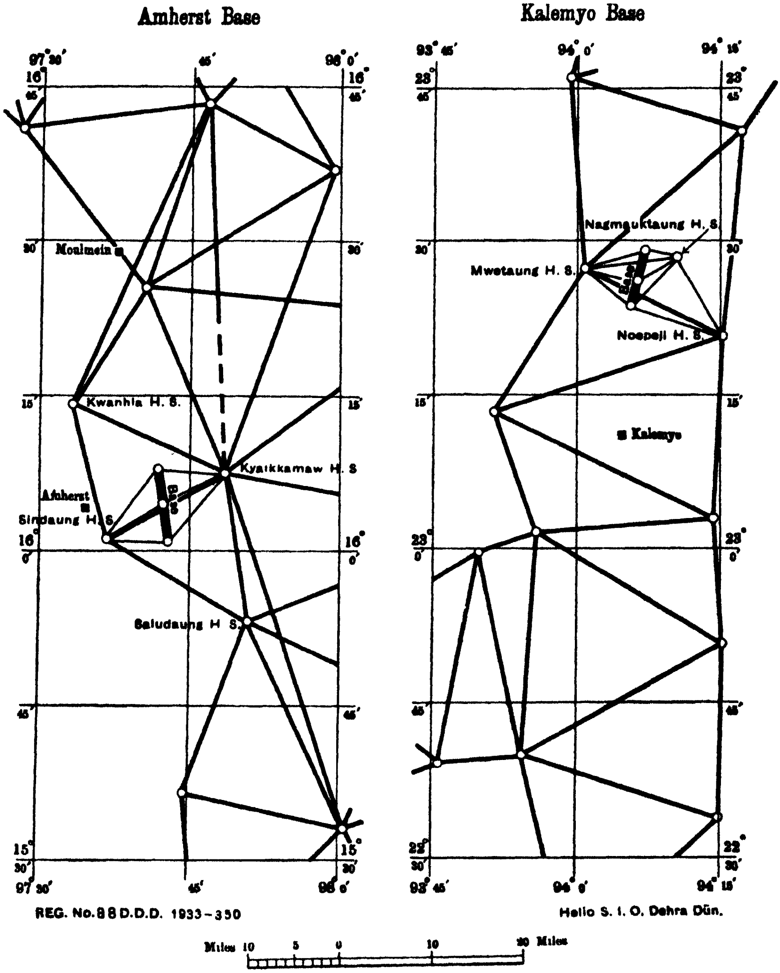


FIG. 33.—Burmese base lines. (From Survey of India, Geodetic Branch Report.)

It is necessary, as a preliminary to contouring, to fix on a starting point at some definite height above sea level. This may be done in various ways. The most accurate method is to fix the height of

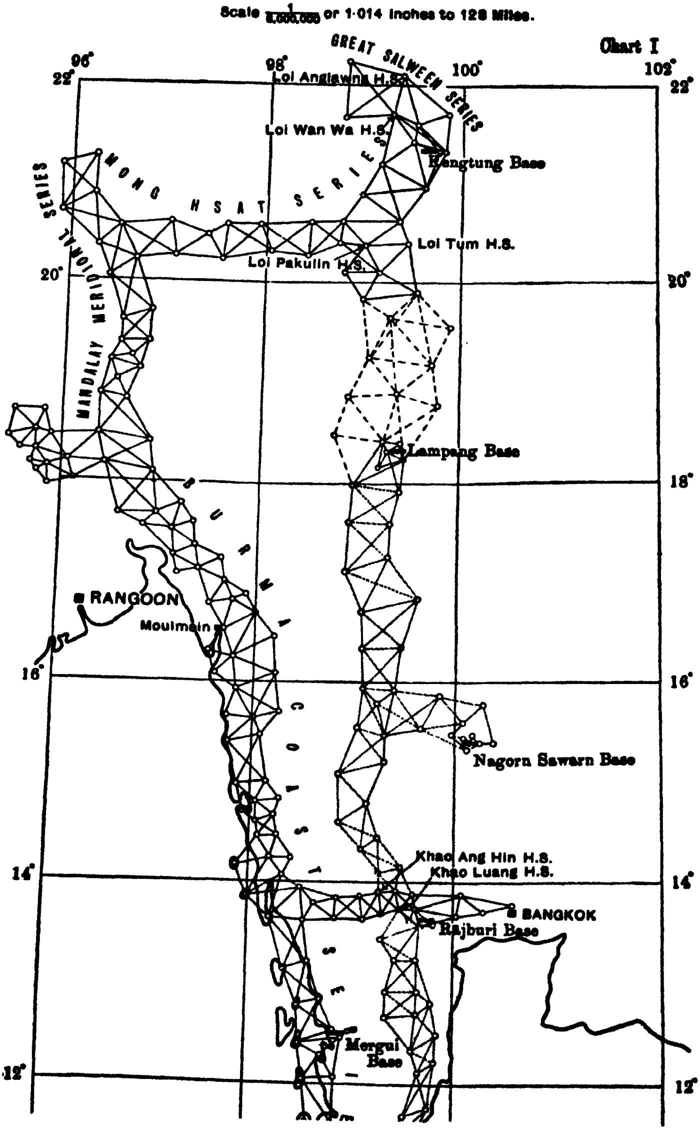


FIG. 34.—Burma-Siam triangulation. (From Survey of India, Geodetic Branch Report.)

important places by careful levelling, using a spirit level and telescope, from the plane of reference that has been adopted. The spirit-levelling operations of the Survey of India in 1882-83, in connection with tidal observations, completed the last link of levels between the sea at Karachi and False Point in the Bay of Bengal. This line was taken from Karachi up the Indus to Mithankot and onwards via Firozpur, Agra, Allahabad, Monghyr and Calcutta to False Point—a distance of about 2300 miles, or as far as from London via Germany to Astrakhan. The error in this levelling does not exceed 1·7 feet, *i.e.* it is under nine inches per thousand miles. Before 1882, accurate sea level as a datum was unknown in the country through which the traverse was taken.

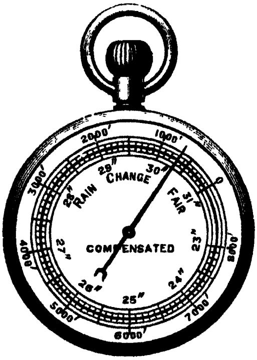


FIG. 35.—A pocket "aneroid" barometer.

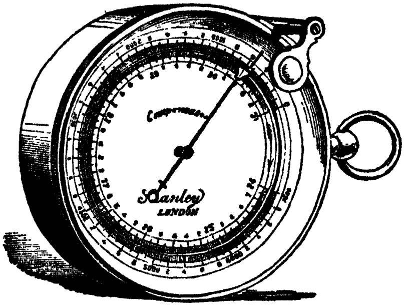


FIG. 36.—Aneroid barometer used in geological surveys and by explorers.

From the spirit-levelling operations the sea heights of numerous points would be fixed, and from some of these points it is possible to determine the heights of conspicuous objects (*e.g.* prominent rocks, cairns on hill tops, the summits of fort towers, etc.) above sea level. For this purpose the vertical angles (called the **altitudes**) which the directions of such objects make with the horizontal are measured (Fig. 32), and the heights are ultimately calculated by trigonometry. In Fig. 27 the horizontal angles from *A* and *B* would fix the position of *C* and *D* in azimuth only, but if the vertical angle *CBD* is also measured, the height of *C*, *i.e.* *CD*, above *B* is easily computed. By an extension of this process, a system of triangles is built up, fixing the precise positions and heights of a large number of points. This is called the method of **triangulation.** Fig. 33 shows the triangulation and base lines in the Amherst and Kalemyo areas of Burma, and Fig. 34 shows the meridonial triangles in Burma which are joined to the Siam triangulation by cross triangles in the latitudes of Bangkok and Loi Tum, thus making a *grid* of triangles and leaving large areas to be filled in later by secondary triangulation.

Another, though less accurate, method which is often used for finding heights depends on the fact that, if the atmospheric conditions remain constant, a barometer carried from a low to a higher level registers a regularly diminishing pressure of the air. For small elevations it is said that a fall of one inch in the barometer-reading corresponds to an increase of about 1000 feet in altitude (Chapter XIV). Fig. 35 illustrates an "aneroid" barometer used for measuring in this way the heights of mountains. The inner circle shows, in inches, the "height of the barometer", which depends (Chapter XIV) on the pressure of the atmosphere; the outer scale shows in feet the differences in altitude corresponding roughly with these changes.

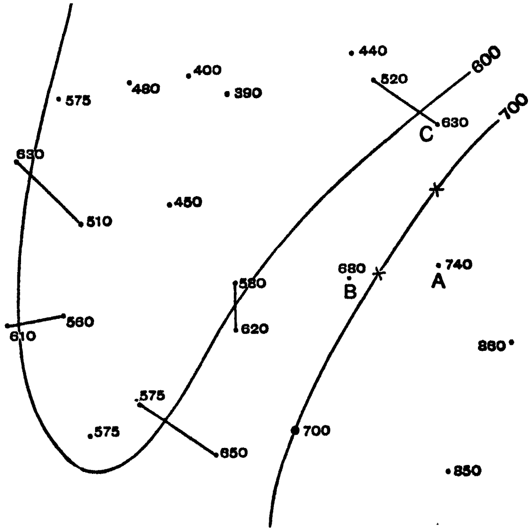
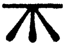


FIG. 37.—Method of drawing contoured diagrams. For explanation see text.

The heights of points having been obtained by preliminary work of this kind, each point is marked by a **bench mark**—a broad arrow with a horizontal line through the point  —cut on a stone wall, strong fence or other suitable fixed object, and the actual heights above the Indian Spring low-water mark are noted in feet and decimals of feet upon the one inch larger scale maps with arrows to show the exact positions of the bench marks. Then the contours are drawn from these marks. For example, if a bench mark is found on the one inch map and the height is given as 1496 feet, the staff is fixed with its lower end on a level with the horizontal part of the bench mark and the levelling instrument is set up. A reading is taken of the mark on the staff which corresponds with the height of the level. Suppose it is 5·2 feet. Then to get the 1500 feet contour the staff must be moved up the hill until the man at the instrument reads 0·76 feet. It is plain that the staff will then have been raised 4·44 feet (since 5·2 – 0·76 = 4·44), and that its lower end will then be at a height of 1496 + 4·44 = 1500 feet. The man at the instrument beckons to the assistant with the staff to move until such a position is obtained exactly. This point fixed is on the 1500 feet contour; it is marked on the map. It is now a simple matter to follow on round, keeping at the same height, to fix other points on the contour. The level itself is moved when the staff is too far off to allow a reading to be taken easily, the staff being kept fixed for the purpose, and the reading being taken again when the instrument is in the new position. Usually it is wise to finish on a bench mark, to see what

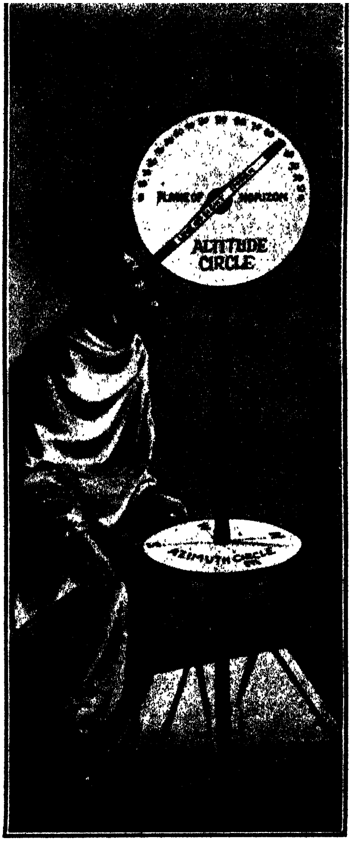


FIG. 38.—The meaning of altitude and azimuth in measuring vertical and horizontal angles. (Taken from Todd's "New Astronomy" with the permission of the American Book Company, New York.)

(Partly redrawn.)

error—if any—has been made. The 1600 feet and other contours are obtained in the same manner.

Contours determined in this way are called **Instrumental contours,** as distinguished from the " sketched contours " seen on the older maps.

Contoured diagrams.—What are known as contoured diagrams may be used to show graphically the distribution, not only of relative heights, but also of temperatures (Chapter XII), atmospheric pressures (Chapter XIV) and other magnitudes. The general method of construction will be understood easily from an example (Fig. 37). In this map one point having a height of 700 feet is given ; two other points (marked by crosses) of the same height are obtained thus. Join *A* and *B* ; the difference between their heights is 60 feet. On the line *AB* a point 20 feet higher than *B* is required. On the assumption that the slope along *AB* is uniform, the required point is clearly $\frac{20}{60}$ or $\frac{1}{3}$ of the distance from *B*. Similarly, on the line *AC*, a point about $\frac{4}{7}$ of *AC* from *A* has a height of 700 feet. A smooth line, drawn through the three points, is the 700 feet contour line.

The V-shaped 600 feet contour line has also been drawn, through points obtained by dividing proportionally the cross lines shown. At the angle of the V, guidance is obtained from the two points marked 575, which are on a contour presumably parallel, or nearly so, with the 600 feet line. The contours of 400, 500, and 800 feet may be drawn in a similar manner from the heights given.

The explanation of the terms Azimuth and Altitude will be clear from a glance at Fig. 38, which is a skeleton representation of the elaborate theodolites used for trigonometrical surveys. Figs. 16 and 17 illustrate normal theodolites used in field surveys in topographical work and for mine surveys. Fig. 21 shows the common level in general use.

5. THE PRACTICAL USE OF MAPS

1. Symbols used in Ordnance maps.—Study the symbols shown on Fig 43, (opposite) and, with their help, from the map of the Cherrapunji area (facing p. 32), make a list of all the trigonometrical points, waterfalls, coal mines, post and telegraph offices, and the end of the motor road from Shillong. There is a slight mistake in the map where the stream from the Mawsmai caves runs down to Ryngud. The bridle path crosses the stream by a natural bridge, which is not shown on a map of this scale. A good example of a stream disappearing underground is that below the word " Ropeway " and above " Therriaghat ".

2. Coloured contour zones.—Copy Fig. 42, and colour the zones between successive contour lines differently according to height: employing various shades of dark green, light green, yellow, and from light brown to dark brown for successively greater heights.

3. Sections along straight lines.—(*a*) Rule a fine pencil line through *D* at right angles to *EF* on Fig. 42. In the manner shown at the foot of Fig. 42, draw a section along the line. Can the point *G* be seen from the point *E*? Can the highest point on the map be seen from *E*?

4. Draw a section from an orographical map (Fig. 26), such as that of the Cherrapunji area, along a straight line from Companyganj to Dympep. What is the least vertical scale which, in your opinion, shows the general configuration of the land satisfactorily? How many times is this greater than the horizontal scale?

5. On the contoured map of Chamba (Fig. 29) draw a fine straight line from the Residency in the town to the saddle at Behi, 5000 feet, roughly 2½ miles away to the south-west. Use a vertical scale of $\frac{1}{10}$ inch to 200 feet, and draw a section along the line. Find out, from the section, whether the summit of the mountain is visible on a clear day from the Residency. If not, how high would a captive balloon need to rise vertically above the Residency to give, to an observer in it, a sight of the summit behind Behi village?

6. Road-book sections.—With a pair of dividers, open so that the points are ¼ inch apart, " step " from end to end of the ropeway seen on the map of Cherrapunji. What is the length thus measured? Why is the real length probably a little greater than this? Could a more accurate result be obtained with the points ⅛ inch apart? Set out the length of the ropeway on a horizontal straight line, on a scale of 1 inch to 1 mile, and on it mark each point of which the height is shown by the contours of the map. At each of these points erect a vertical line, using a scale of heights $\frac{1}{10}$ inch to 100 feet, and join the upper ends of the verticals.

Conventions used in Survey of India maps.—The Survey of India maps are not in any sense an attempt to portray a tract of country as it might be seen from an aeroplane passing overhead. By means of a number of ingeniously devised symbols, the map conveys a great deal of information concerning features which would be indistinguishable in the best photographs that could possibly be taken

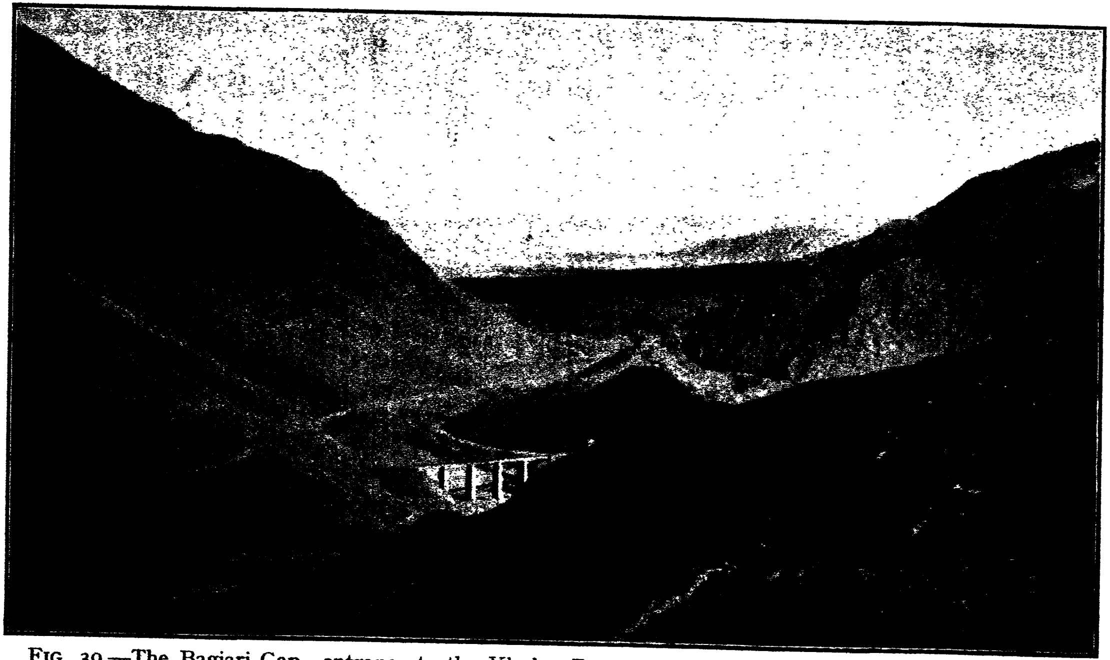


FIG. 39.—The Bagiari Gap—entrance to the Khyber Pass. View eastwards towards Jamrud from below Shagai. The railway (bridge), military road and caravan road are seen in the picture. (With the permission of the Director, Geological Survey of India. Photo by C. S. Fox).

from above on the same scale. Fig. 43 shows the symbols employed on the Survey of India maps, and intended for use with most of their maps—from the standard one-inch maps to those of the Degree or quarter-inch and one-millionth sheets.

The use of the Survey of India maps may be illustrated by the following account of some of the facts shown in a fairly complicated map—that of the Afghanistan sheet facing p. 38. The Swat river comes down from north of Malakand and flows round by Abazai to Charsadda, where it joins the Kabul river. The Swat river canal takes off at Abazai, and irrigates nearly 240 square miles of the dry Yusufzai plain between it and the Kabul river. Recently a weir has been made across the Swat river at Chakdarra, above Malakand, and the water led through a pressure tunnel from Malakand to Dargai, from which place the Yusufzai country north of the Abazai canal is now irrigated.

FIG. 40.—View down the Hooghly from the Water Gate bank, Fort William, Calcutta. (Photo by C. S. Fox.)

From a military point of view the importance of the Kurram is worthy of notice, although it is flanked by the tribal area of Tirah on the east and Afghan territory on the west. Lord Roberts went to the relief of Kabul from the Kurram, through Parachinar, in 1879, as it is the shortest distance to Kabul from British India. To the north of Parachinar is the snowy range of the Safed Koh (white mountain) and beyond lies the historic area of Jalalabad. The modernisation of Afghanistan may be noted from the post and telegraph offices of Jalalabad and Loe Dakka and the telephone line up the Kunar valley from Jalalabad to Asmari and Birkot. It is hoped that the railway through the Khyber Pass will, in the near future, be extended to Loe Dakka and Jalalabad, and ultimately to Kabul. Metre guage railways extend from Kohat to Thal in Kurram and from the Kurram, at Bannu, to Kalabagh on the Indus, where a fine bridge has been recently erected (Fig. 117).

Fig. 41 (opposite) is part of the Calcutta sheet, No. 79, of the India and adjacent country series, of the Survey of India, on a scale of 16 miles to an inch (roughly one millionth) It shows the river Hooghly from above Barrackpore to beyond Dublat at the toe of Sagar island. Fig. 40 is a view of the Hooghly at Fort William, Calcutta and Fig. 124 is a view on the opposite (Howrah), shore during a bore. The three important tributaries of the Hooghly —the Haldi, the Rupnarayan and the Damodar—on the west or right bank are shown. The Rupnarayan comes in opposite Hooghly Point, and just about this confluence are the notorious " James and Mary Shoals ", where many a ship lies buried. The low swamp, or lagoon, of the Salt Lakes is seen south-east of Calcutta and also the Bidyadhari channel, which passes Port Canning (Matla) and becomes the Matla estuary. The sewage and storm water from Calcutta passes into the Bidyadhari, which is a tidal channel.

The inland navigation of the Ganges, Megna and Brahmaputra rivers is conducted by steamers which leave Calcutta and pass through the creeks of the Sundarbans—the coastal strip of the Ganges delta—to the Padma. At one time, within the historic period, the Hooghly, as the Saraswati, occupied a course west of its present position. The old channel is still recognisable and is marked through the *S* of *S*erampore, and so to the Rajganj bend of the Hooghly above the *A* of *A*lipore.

In the four types of the Survey of India maps, facing pages 32, 36, 38 and 50, contours are always put in where the land is not too low-lying, as is the case in the Ganges delta. On the one-inch to the mile ($\frac{1}{63360}$, very nearly $\frac{1}{62500}$) maps, the contours are drawn at 100-foot vertical intervals. On the quarter-inch, Degree sheets ($\frac{1}{253440}$, very nearly $\frac{1}{250000}$), the contours are at 250-foot vertical intervals. The maps of 16 miles to an inch (1·014 inches, or one-millionth) have conis then dropped, to cut these, from each point where the line of section crosses a contour on the map. In joining up the surface points thus obtained, to give the required line of surface, special care is necessary where the line of section crosses the same contour repeatedly.

Exactly the same method is followed in drawing a section across a country or continent from an ordinary orographical map. In this case the contours are represented by the lines separating differently coloured areas on the map.

Very erroneous impressions of the nature of the surface will be gained from the use of such sections unless the exaggeration of the vertical scale be borne in mind.

It may be desirable sometimes to know whether one point shown on a contoured map is visible from another ; whether, for example, the point *G* in Fig. 42 would be visible from the point *E*. A section (the scale is immaterial) along a *straight* line connecting the two points at once answers the question.

Sections along winding lines.—In **road-book sections** prepared for cyclists and pedestrians, the route, however it may wind about in reality, is shown as if it lay along a straight line of the same length, and a vertical scale is chosen which renders obvious all important changes of gradient. The same method is often employed (p. 47) to show the changes in slope along the course of a river ; such a diagram is called a **river profile.**

Map references to positions.—The position of a ship at sea is always stated in terms of latitude and longitude. The geographical index in an atlas gives the position of the places named in terms of latitude and longitude, often to the nearest minute. The one-inch to the mile maps of the Survey of India permit of the latitude and longitude, *i.e.* the parallel and meridian, of a place to be determined to the nearest second. Thus from the sheet which includes Calcutta the map reference of the Meteorological Office in Alipur was ascertained as 22° 31′ 27″ N. : 88° 18′ 32″ E. In the " Discussion on Ordnance Survey Maps " (*Geographical Journal*, vol. lxxxvii, No. 4, April 1936, p. 316). Col. B. K. Boulnois is recorded as saying—" The Royal Air Force are saying to me, 'Please leave off all grids on our maps ; we much prefer the graticule.' The graticule, as I feel sure is well known, is the system of parallels and meridians by which reference to position can be given. It is used by sailors and has world wide application."

Military experience, however, has shown that the **graticule** method of giving map references is unsuitable both for artillery purposes and signalling operations. For example in sheet $38\frac{L}{6}$ (3rd Sept. 1928), which covers an area between 32° 30′ to 32° 45′ (N. latitude) and 70° 15′ to 70° 30′ (E. longitude), the mosque at Kot would be indicated precisely as in 70° 21′ 30″ E.; 32° 35′ 10″ N. This is a cumbersome map reference to signal where brevity might be urgently desirable in the stress of fighting. An effort was made to letter and number the squares of the graticule, so that the top left-hand corner square was A. 1. the next to the east of it B. 1 and the one south of A. 1 as A. 2, etc. If each side of the squares was divided into tenths a position within would be briefly given by the square letter and figure and the co-ordinates of the sides of the square involved. But such a system would fail if more than one map sheet was employed since each of the adjacent sheets would also have the squares lettered and numbered in the same way. The need for a special sheet number would thus arise and the value of the method largely spoilt.

To overcome the disadvantage above referred to, the map sheet, say $38\frac{L}{6}$, is divided into one-minute squares by the graticules of longitude and latitude and made into a **minute mesh map.** Groups of 10 minute squares are given letters *A*, *B*, etc. to *Z*, arranged horizontally in rows of six, one below the other, and a larger series of letters given to each set of lettered-10-minute squares. Further, each lettered-10-minute square is numbered 00 from the S.W. corner, and places within thus located by co-ordinates as in the method previously described. Thus if the *mesh map* of sheet $38\frac{L}{6}$ is procured it will be seen that the position of the mosque at Kot is fairly located by the map reference Tc 15, and, fixed accurately, by Tc 15051.

It will be found that each one-minute square on sheet $38\frac{L}{6}$ measures W. to E. (longitude) approximately 1710 yards and S. to N. (latitude) 2021 yards. Unfortunately these measurements are not reliable for all parts of the map sheet. The squares are not true squares since they are formed by the intersection of north-converging meridians across parallels. However, in Major Bomford's " Monograph on the Lambert Grid for India ", 1930, (Survey of India), it is stated : " Although a system of equal squares cannot be drawn on the Earth's surface, such a system can easily be drawn on a map, or series of maps whose edges fit together. Such a reference system is called a " grid ", and it is normal after the projection of the map on which it is supposed to be drawn. Thus a Mercator grid is a set of squares ruled upon a Mercator map."

Also, " The Army requires a grid for two reasons, *viz.* : (*a*) for map references, and (*b*) for R.A. and Survey computations. So far as map references are concerned the question presents little difficulty: the essentials are that references should be brief, precise and unambiguous, and that the reference system should not unduly disfigure the maps. The pre-war method was to give such a reference as ½ mile N.N.W. of the *R* in *R*aipur. Such a reference is neither brief, nor precise, and it may be ambiguous. The best reference system is a set of squares or rectangles ruled on the map, with reference to which the positions of points are described by ordinary East and North or *X* and *Y* co-ordinates (*X* for eastings and *Y* for northings) . . . the Indian Minute Mesh (Indian Army Order No. 724 of 1924), in which the rectangles were the geographical meridians and parallels. The system of map references now adopted is that of the ' Modified British Grid '. "

If the **Grid Map** of sheet $38\frac{L}{6}$ is procured it will be at once seen that the grid ruling is not parallel with the meridian and that the mean **Grid North** in this sheet is 1° 17′ east of True North, while the mean Magnetic Declination is 2° 55′ E. (decreasing by 3′ annually). The incidence of Letters on Grid is *X*. The following is the method used to give a reference on this map:—

Letter : See diagram of Incidence of Letters on Grid.

Figures : disregard the smaller figures in the border, which gives full co-ordinates from origin, viz. 3240000. Use the *Larger* border figures or those printed on the face of the map.

Point : Kot (mosque).

Letter X : The letter will only be used when specially ordered.

EAST		NORTH	
Take line west of *Point*, and read figures printed against it in north and south borders, or on the line itself on the face of the map	41	Take line south of *Point*, and read figures printed against it in east and west borders, or on line itself on the face of the map	13
estimate tenths eastward	8	estimate tenths northwards	0
East	418	North	130

Reference 418130

This is not the place to give a detailed description of the Lambert Grid for India, nor to discuss other theoretical aspects of Grid maps, but the student is advised to secure copies of the normal or graticule map, the same map with Minute Mesh and also a copy of the same sheet with the Lambert Grid. He will quickly discover the manner of giving map references and find the old graticule map is undoubtedly still the most convenient for normal purposes whatever may be the value of the Grid map for military purposes. The Minute Mesh map is now obsolete.

For further work on the subjects of Chaps. I and II, the War Office "Manual of Map Reading and Field Sketching" (1s. 3d.) is strongly recommended. The pleasures to be obtained from the use of maps are admirably described in C. E. Montague's "The Right Place" (Chatto & Windus, 3s. 6d.), which should be read by every student of geography. Excellent examples of varied types of British Indian topography are to be found in the Atlas sheets of the Survey of India by choosing certain areas such as Simla, Delhi, Bombay, Calcutta, Madras, Nagpur, Ajmir, Karachi, Lucknow, Ranchi and Shillong. For "The Study of Geological Maps" Dr. Gertrude L. Elles' book of this name, published by the Cambridge University Press, is recommended.

EXERCISES ON CHAPTER II

1. If you were given a contoured map on which the summits of two hills are marked *A* and *B*, and were asked to draw a section along the straight line joining *A B*, how would you set about it? What is the use of a section of this kind?

2. A gently-sloping region terminates upwards in a broken ridge, the peaks of which rise to heights of over 2000 feet above sea level. The region is drained by the upland tributaries of a great river. By means of contour lines represent such a region.

3. Explain what is meant by contour lines.
A lake lies 1000 feet above sea level, and is surrounded by high lands rising steeply from its shores to a height of 1300 feet above sea level, but sloping gradually on all sides down to the sea 50 miles off. Draw a sketch map, and show this by means of contour lines.

4. A stream, flowing along a steep-sided valley in a hilly district, is dammed for a reservoir just below a point where several feeders join the main stream. When filled, the level of the water in the reservoir stands at 400 feet O.D. Draw a map of the district and reservoir, using contour lines.

5. A village is situated at the crossing of two straight roads, one of which runs due N.-S. 100 yards up the road to the N. stands the church, and at half that distance down the S. road stands the village post office. Between the two S.-trending roads is the village green ; its S. boundary, 60 yards long, begins by the post office and runs at right angles to the road on which the post office stands. 40 yards beyond the village green on the road, which runs roughly south-west, where the railway crosses the road at right angles by a bridge, is the railway station. Draw a map of the village to a scale of 20 yards to one inch, using Survey of India symbols.

6. *A* and *B* are two church spires 5000 feet apart, *B* lying due east of *A*. From a third point *C* it is observed that *A* lies exactly north-west, and *B* north-north-east. Draw a rough plan, showing approximately the relative positions of *A*, *B* and *C* ; and explain how, with the aid of a graduated rule and a protractor measuring angles, you would proceed to draw a plan accurately to scale.

7. Examine the accompanying Survey of India map (part of the one-inch sheet, No. 52 D/2 with Chamba) and in your answer book:

(*a*) Draw a section showing the country along a line from Chamba to the ridge of Chatren, making the vertical scale about 1 inch to 800 feet.

(*b*) State how many tributaries converge on the Ravi river within a mile of Chamba town, and how they differ from one another.

(*c*) Show how you could discover that the map is on the scale of one inch to one mile, if the scale were not printed at the foot.

(*d*) Estimate in miles the distance of the upper bridge from the power-house near the lower bridge north of Chamba and explain how you judge this.

8. Draw a sketch showing a piece of main road which crosses a deep cutting, then passes over a stream by means of a bridge, next goes through a short tunnel, and on coming out of the tunnel passes under a railway bridge and over a canal. The railway crosses the road and canal at equal angles, *i.e.* at 45° to each.

N.B.—Use the conventional signs employed in the maps of the Survey of India.

9. In cycling through the village of *X*, I ask my way to the village of *Y*. I get the following directions :

" Go down the village street for about a quarter of a mile till you come to the church, which is on your left hand ; turn sharp to the right, cross the bridge over the railway ; turn to the left, and then follow the road running alongside the railway for two miles till you come to four cross-roads, in a wood, just after crossing a bridge over a stream. Turn to the right, and keep to the road beside the stream for a mile ; you will see the village of *Y* close by on your right."

Draw a rough sketch map which would help me to remember these directions.

10. Describe briefly how you would measure : (1) the length of a level road ; (2) the slope of a road.

11. Represent the following on a map, using contour lines for the hills : A valley running more or less north and south, with hills on the west rising to 800 feet and on the east to 600 feet. A stream flows along the valley, entering at a height of 500 feet and leaving at 200 feet. There is a small side valley on the east, partly filled by a mountain lake. There is also a railway in the lower half of the valley, with a walled-in road, which is an open moor road in the upper half of the valley.

12. On the accompanying map (Fig. 42) the configuration of the ground is shown by contour lines at vertical intervals of 30 feet. A stream runs from *A* to *B* and is joined by tributaries at *C* and *D*. Show by thick lines the probable courses of the stream and its tributaries, and draw a vertical section of the country from *E* to *F* in the space provided below the map.

13. Draw a contour map of an imaginary island. Let the highest point, 1500 feet, be somewhere near the centre. Fill in imaginary contour lines at 100, 400, 700, 1000 and 1200 feet. Let the steepest part be on the west.

14. Describe briefly how maps are made, giving special attention to methods of marking elevation above sea level.

15. Draw a contoured map of a ridge 2 miles long and ½ mile broad, running east and west. The top of the hill is a plateau 400 feet high, 1 mile long and ⅛th mile across, and the descent is steeper on the south side than on the north. Draw the map to a scale of 2 inches to the mile, and show contour lines for every 100 feet.

16. Using the signs employed in the maps of the Survey of India, make a sketch showing a forest composed of coniferous and deciduous trees through which passes a footpath. On emerging from the forest the footpath crosses a river (which bounds the forest on the north and east sides) by means of a stone bridge. It then crosses a narrow meadow and joins a metalled road which at this point is running in a north-westerly direction, having previously a westerly direction : standing at this angle in the roadway is a church with a spire, while to the north of the roadway is a marsh. Some distance to the west of the church the road crosses a railway at a level-crossing, the railway being at right angles to the direction of the road.

17. Draw a sketch-map showing the following features by means of contour lines and the symbols used by the Survey of India (a scale must be shown). The eastern half of the country to be represented is a plateau with a steep escarpment facing west. and a gentle slope to the east. The height of the escarpment is 500 feet ; it descends abruptly westwards to an undulating plain 50 to 200 feet above sea level. A broad river meanders through the plain with a general direction from north to south ; it is joined by a tributary stream which has excavated a valley in the plateau and cuts through the escarpment. At the junction of the stream with the main river is a town with a church. In the plain there are extensive oak-woods (deciduous), and on the dip-slope of the plateau there are clumps of coniferous trees.

CHAPTER III

MAP PROJECTION

6. LATITUDE AND LONGITUDE

1. A point on a sphere.—Obtain a number of balls (spheres) of various sizes, such as a marble, a billiard or ping-pong ball and a tennis ball. Select one if possible with no marks on its surface and make a dot on it. If you were asked to mark a second plain sphere with a dot in an exactly similar position, would you consider the request reasonable? If not, why not?

2. The axis and poles of a sphere.—Select an orange approaching the spherical shape as nearly as possible. Notice the scar where the stalk of the fruit was fixed, and exactly opposite, on the other side of the orange, a dot. Stick a darning needle through the orange, so that it passes through both these points, which may be called the *poles*. Make the orange rotate by twirling the needle between finger and thumb. Mark the surface in various places by attaching small pieces of gummed paper, and rotate again. What kind of curve is marked out by the motion of each bit of paper? Which piece of paper moves over the greatest path during one rotation? During one second of time? Which moves over the least? Which piece rotates most quickly? Which most slowly? Are there any points on the surface of the fruit which do not rotate at all?

Take out the needle and reinsert it at one pole, but push it through the orange in a different direction, so that it comes out a little distance from the other pole. Twirl the needle again; what difference do you observe in the rotation of the orange?

3. Great and small circles.—Roll a lump of plasticine between two boards until it is as nearly spherical as you can make it. Cut out of stiff cardboard a circular hole just, but only just, large enough for the sphere to pass through. Divide the edge of the circular hole, that is, the circumference of the circle, into 12 equal parts, and mark the points as in Fig. 44. Push a needle carefully through the centre of the sphere and lay the sphere in the hole so that the projecting ends of the needle both rest on the same side of the card, at the points marked 90°. Neglecting the thickness of the needle and card, what fraction of the sphere is on each side of the card? What name is given to half a sphere? Hold the sphere still, and mark a line on its surface by running a pencil point gently along the edge of the hole in the card.

What is the shape of the line? A circle drawn on the surface of a sphere and dividing it into hemispheres is called a *great circle.*

Place the pencil point at one of the points marked 0° on the card and, keeping the poles at 90°, rotate the sphere once in the hole so as to mark a circle on its surface half-way between the poles.

It is called the *equator.*

Is the equator a great circle? In the same way, trace circles on the sphere parallel to the equator, through the points marked 30° and 60° on the card. Are these also great circles?

These circles are called *parallels of latitude.*

Lift the sphere and replace it in the hole so that the equator lies in the plane of the graduated card, with the first circle (marked as described above) intersecting it at 0°. The needle will then be perpendicular to the plane of the card. Mark also on the equator the positions of the other points shown on the card. Replace the sphere in the hole in its first position, and rub the pencil point around the edge of the hole to draw great circles through the marked points crossing the equator. Notice that all these, like the first circle drawn, pass through the poles.

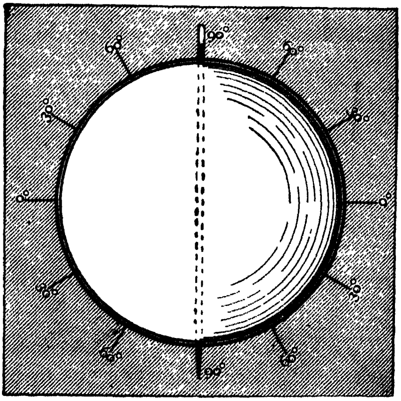


FIG. 44.—To illustrate Expt. 3, Section 6.

Great circles passing through the poles of a sphere are called *meridians.*

How many meridians could be drawn on the same sphere? Take out the model and study the network of lines on its surface. Preserve it for use in Expt. 5 (*c*), p. 62.

Given a sphere on which the poles and one meridian were already marked, could you now devise a method of stating exactly the position of any dot on its surface?

4. The graduation of the circle.—Examine a semicircular protractor and compare its method of graduation with that of the equator on a terrestrial globe. Find on the globe the meridian passing through London (Greenwich) and notice that its intersection with the equator is the zero point on the latter.

The *longitude* of any place is specified by the point at which the meridian of the place cuts the equator.

Also notice how *latitude*—*i.e.* the angular distance north or south of the equator—is expressed on the terrestrial globe.

5. Examples in latitude and longitude.—Find on the terrestrial globe what occupies each of the following approximate positions: (*a*) lat. 53° N., long. 13° E.; (*b*) lat. 22° N., long. 88° E.; (*c*) lat. 16° S., long. 6° W.; (*d*) lat. 22° N., long. 114° E.; (*e*) lat. 35° S., long. 58° W.

6. Antipodes.—Write down the latitude and longitude of the antipodes of the above positions (*i.e.* the points on the other side of the globe at which straight lines passing through them and the centre would cut the surface).

Preliminary considerations.—The earth is so nearly spherical that for our present purpose we may ignore any departures from this shape which it presents, although this question must be referred to again in later chapters. Now, a little thought will show that in any attempt to specify the position of a given point on a sphere (for example the position of a certain town on the surface of the earth), the perfection of symmetry of the globe is in itself a source of difficulty, for, in order to describe position, we must plainly have some well defined points to which distances and directions may be referred. On the surface of a sphere in general there is no point which is distinguished inherently from other points.

Our earth, however, is not at rest; besides having other motions, it is constantly spinning, or rotating, in a very regular manner, somewhat as a small sphere of cork or plasticine might be made to rotate if a needle were thrust through its centre to represent the **axis** and then twirled between finger and thumb. On the surface of such a spinning globe two points called the **poles**—the two points at which the axis comes to the surface—take no part in the spinning motion ; while all other points on the surface rotate in circles of size depending on their distance from the poles. The greatest of such circles is that described by any point half-way between the two poles.

The poles of a spinning globe—thus distinguished from all other points on its surface by being at rest—may evidently be used as the points of reference we are seeking. Their employment in this manner for geographical purposes immediately becomes clear on examination of a model globe representing the earth.

Latitude and longitude.—Such a " terrestrial globe " is covered with a network of numbered reference lines consisting of two sets of circles (Fig. 45). All the circles of one set—called **meridians** or lines of longitude—pass through both poles, and the centre of each is the centre of the sphere itself. They are evidently as large as any circles drawn on the surface of the sphere can possibly be. For this reason the meridians are called **great circles.**

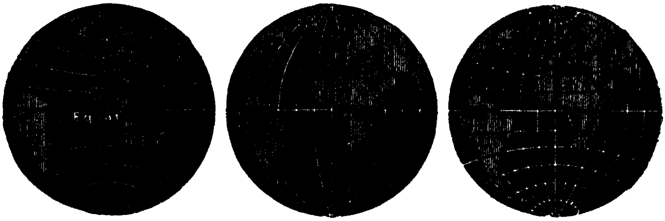


FIG. 45.—Parallels of latitude and meridians of longitude, separate and combined.

Of the other set of circles—known as the **parallels of latitude**—only one is a great circle. This is called the **equator** ; it passes round the globe half way between the two poles, and consequently bisects each meridian. The remaining lines of latitude are " small " circles parallel to the equator ; they are shown at equal intervals between the equator and the poles. Their centres lie on the axis of the sphere at intervals between the centre of the sphere and the poles.

The numbering of the lines depends on the familiar method of referring to an arc of a circle in terms of the angle subtended by the arc at the centre of the circle. For example, $\frac{1}{360}$ part of the circumference of a circle is referred to commonly as *one degree of arc*, because it subtends an angle of one degree (1°) at the centre. On the same principle, $\frac{1}{4}$ of the circumference of a circle is referred to as 90° of arc, $\frac{1}{2}$ as 180°, and so forth. Similarly, $\frac{1}{60}$ of a degree of arc may be called 1 *minute* (1′) of arc, and $\frac{1}{60}$ of a minute 1 *second* (1″) of arc.

The great circle called the equator is graduated in this manner, the zero point most commonly used being the point at which the meridian passing through Greenwich—called the **prime meridan**—cuts the equator. Any other meridian is distinguished by the angular distance between the zero point and the point—east or west of it—where the meridian in question cuts the equator. Thus, the meridian 82° 30′ east of Greenwich is that meridian which cuts the equator 82° 30′ of arc to the east of the zero point, and all points on it are said to have a longitude of 82° 30′ E. It is obvious that the meridian 180° W. is also 180° E., and that this and the prime meridian are halves of the same great circle.

Any meridian may be taken as zero instead of that of Greenwich, but when no zero is specified that of Greenwich is understood.

The arc of a meridian between the equator and a pole is one-quarter of a great circle, and is graduated into 90° (*i.e.* $\frac{360°}{4}$) from the equator, northward or southward as the case may be. Thus, a place is described as of latitude 22° 30′ north, if it lies on a line of latitude (parallel to the equator) which cuts the meridian of the place at a point 22° 30′ to the north of the equator—*i.e.* $\frac{1}{3}$ of the distance, measured along the meridian, from the equator to the south pole. The latitude of the equator is 0° ; that of each pole is 90°.

Antipodes.—Points are said to be antipodal to each other when they are at opposite ends of a straight line passing through the centre of the earth. Obviously one is as much north as the other is south of the equator, and lies on a meridian which is 180° of arc from the longitude of the other. Thus a point of lat. 24° 30′ N., long. 76° 30′ E., and one of lat. 24° 30′ S., long. 103° 30′ W., are the antipodes of each other.

It should be clear that when the latitude and longitude of any place are both known, the position of that place can be marked on a globe accurately. Thus the exact position of the observatory at Madras is given as 13° 4′ 8″ N. lat. and 80° 14′ 50″ E. long. in the Nautical Almanac for 1932. In Chapter IV, methods will be explained by which explorers or sailors are able to determine the latitude and longitude of their positions. Given the positions of a sufficiently large number of places, as determined by the observations of explorers, it is therefore possible to draw the map of any country, or even of the world, *on a globe*.

7. THE PRINCIPLES OF PROJECTION

1. Cut out small squares of tracing-paper, say of 1 in., ¾ in., ½ in. and ¼ in. side respectively, and apply them in turn to the surfaces of terrestrial globes of different sizes. Notice (*a*) that although the paper is flexible, only a very small piece can without creasing be in such entire contact with the globe as would be necessary for accurate tracing; (*b*) that the smallest piece needs the least creasing to ensure contact; (*c*) that the same piece of paper is creased less on a large globe than on a small one.

2. Take a small hollow india-rubber ball, cut out a small piece having four equal sides, and then stretch out the piece on a flat sheet of paper. Run the point of a pencil round the edge and then allow the piece to resume its former shape. Compare the pencil outline with this shape.

3. The orthographic projection.—(*a*) If possible, construct or obtain a globular wire cage, about 9 in. in diameter, the wires representing respectively meridians 30° apart, the equator, and the parallels of latitude 30° and 60° N. and S. The construction will be understood easily on examination of a wire gas-flame protector.* Hold the cage in the sunlight, and observe and draw the shadow cast on a screen behind it, (i) when the shadow of one pole exactly overlies the shadow of the other, and the axis is perpendicular to the screen; (ii) when the screen is as before but the axis is parallel to it.

(*b*) Copy Fig. 46 on twice the scale, drawing by freehand the elliptical curves representing meridians. How many times greater is *Oc* than *ba*? Place transparent squared paper over your drawing, and compare the areas of the meshes H, K and L, which of course represent equal areas of the globe-surface.

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* The accurate apparatus devised by Prof. A. J. Herbertson (and sold by Messrs. George Philip and Son, Ltd., 32 Fleet Street, London, at 21s.) may be used with great advantage.

(*c*) Draw an *" equal area " modification of the orthographic projection* by making OP and PQ each one-third of the distance from O to the pole, and ab, bc and cO each one-third of aO ; and satisfy yourself, by using transparent squared paper, that areas are correctly represented on it.

Difficulties to be overcome in map-drawing.—The advantages of being able to represent any part of the earth's surface, not on globes only, but also on plane (*i.e.* flat) sheets, are so great that geographers have given special attention to the best means of doing it. Perhaps the method which would most naturally suggest itself is that of transferring outlines directly from the globe to the plane surface by tracing, or by some " printing " process. Except for very small areas, however, this is impracticable, for it is impossible without distortion to spread out on a plane surface any part of a spherical surface, even if it is elastic. It is equally impossible to make a plane surface—say a sheet of paper—fit quite accurately on any part of a spherical surface.*

Although some amount of distortion, either of shape or size, is thus inevitable in any attempt to represent a portion of a spherical surface on a plane, it is nevertheless fairly easy to draw a map on which one selected feature at least shall be accurately shown, although other features are of necessity incorrect. In maps of the world on Mercator's projection, for example, the *shapes* of the countries are drawn correctly ; on the other hand, the *scale* varies enormously in different parts of the map, so that an entirely misleading impression of the relative *areas* of different countries is conveyed to anyone studying the map without knowing the principles on which it is drawn. Conversely, maps of the world drawn by other methods may display all areas to a correct scale while at the same time they show countries seriously distorted in shape. In general, it may be said that all plane maps of large sections of the globe are inaccurate in some one respect at least.

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* Col. Valentine Blacker of the Survey of India early drew attention to the fact that the sheets composing the map of any great area should, to ensure accuracy, be projected so as to lie, when joined together, on a *spheroidal* and not a flat surface, and in 1825 he induced the Government of India to accept this proposition and to put it into practice.

The smaller the area to be represented, however, the less pronounced is the curvature of the earth, and consequently the easier it is to approach entire accuracy. Indeed, the whole of India south of the latitude of Shrinagar can be plotted with a maximum linear error of 2 per cent.; while in the one-millionth Survey of India maps of the series of India and adjacent countries, which extend from latitude 36° 30′ to 8° N. and between longitude 68° to 104° E., the maximum linear scale error in each sheet is probably less than 1 in 800, and the greatest local error is the same, and for the whole of India it is probably less than 1 in 100.

Map-projection.—It is obvious that what is required is really a representation, on a plane surface, of the network of lines of latitude and longitude with which the terrestrial globe is covered. When this has been obtained, the filling in of the details of the map is a relatively easy matter. Such a representation is best called a **map-network.** It is more commonly known as a **map-projection,** because some of the simpler networks in use are obtained by geometrical methods of projection. To understand the process, let us suppose that we have a globular cage made of wires which occupy the positions of certain of the lines of latitude and longitude. The shadow of the wires, cast upon a flat screen by a light, is, in the strict geometrical sense, a projection of the case. It is, however, clear that the shadow will differ in appearance according to the position of (1) the light, (2) the screen.

Orthographic projection.—If the source of illumination is at an infinite distance (as would practically be the case if sunlight were employed), so that the light rays are all parallel, and the screen is a plane at right angles to the direction of the light, the shadow forms a map-network known as an **orthographic projection.**

If the wire skeleton earth be turned so that its north pole is directed towards the sun, with its axis parallel to the direction of the light, the shadow formed on the screen will be like Fig. 46A. If, on the other hand, the model be so placed that its axis is at right angles to the direction of the light rays, the shadow on the screen will have the appearance of Fig. 46B. The two diagrams, so drawn, may be said to be projected from each other; they represent the same model as seen from two different directions, which are at right angles to each other.

The diagrams show clearly that parts approaching the edge are represented on an increasingly smaller scale; so that, on Fig. 46A. *Oc* is greater than *cb*, and *cb* greater than *ba*, although the actual distances they represent are in fact equal; and the unequal meshes *H*, *K* and *L* on the map represent equal areas on the globe. Again, in Fig. 46B, *NQ* is greater than *QP*, and *QP* greater than *PO*, though these three lines also represent equal distances.

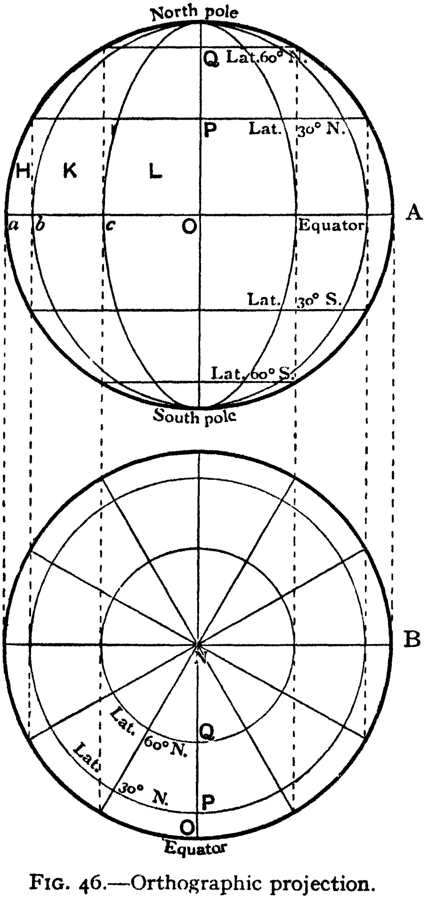

FIG. 46.—Orthographic projection.

In the orthographic projection of a hemisphere as seen from the "side" (*i.e.* in a direction at right angles to the axis) the parallels of latitude are straight lines, while the meridians are for the most part ellipses (Fig. 46A). In the orthographic projection of the polar regions (Fig. 46B) the parallels of latitude are concentric circles, and the meridians are radiating straight lines.

It is clear that a true orthographic projection such as has been described would be practically useless except for regions falling very near the centre of the map. It is usually selected for maps for the exploration of the polar regions.

Modifications of the orthographic projection.—A modification of the orthographic projection, in which all the distances along meridians are true to scale, could be constructed easily. Measurements along parallels of latitude, however, would in this case be inaccurate, and consequently areas would not be proportional.

On the other hand, a " projection " in which the equator also is divided into equal parts, and ellipses (drawn through the points of section and the poles) represent the meridians, does display **areas to the same scale** throughout, although the shapes of countries near the edge of the map are necessarily distorted.

The orthographic projection and its modifications have been discussed at greater length than their intrinsic merits warrant, because they serve very well as an introduction to methods of obtaining the far more useful map-networks which must be considered next.

8. THE PRINCIPAL METHODS OF MAP-PROJECTION

1. The gnomonic or central projection.*—(*a*) In a darkened room place the skeleton globe against a wall, with its axis parallel to the wall. Hold the flame of a lighted taper (or, better, a small movable gas-flame) as near the centre of the model as possible, and observe the appearance of the shadows of the meridians and parallels respectively.

(*b*) Hold the model against the wall with its axis perpendicular to the wall, and repeat the experiment.

(*c*) Copy Fig. 47 to twice the scale.

2. The stereographic projection.—(*a*) Place your eye close to the equator of the wire model, and observe and describe the appearance of the meridians and parallels respectively of the opposite hemisphere.

(*b*) Taking one pole as the point of projection, project on paper the map-network of the opposite half of the globe. In what respect is this method superior to the gnomonic projection of the polar regions?

3. The equidistant or globular projection.†—(*a*) Place the skeleton globe against the wall of a darkened room, with the axis parallel to the wall, and move a small flame backwards and forwards until you obtain the position at which the shadow seems least distorted. Measure the distance of the flame from the globe. What decimal of the radius of the globe is this distance? How does your result compare with 0·707, the value of $\frac{1}{\sqrt{2}}$?

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* The Gnomon of the Greek astronomers was an instrument consisting essentially of a vertical rod standing in the centre of a horizontal floor. The direction of the shadow of the rod cast by the sun determined the sun's azimuth, while the length of the shadow divided by the height of the rod gave the tangent of the sun's zenith distance. The direction of the meridian was found as discussed on page 3, and is a similar problem to that of graduating a sun-dial.

† This is also known as the External (Clarke's) projection.

4. Simple cylindrical projection.*—(*a*) Obtain a piece of tracing-paper about 30 in. long and 6 in. wide, and roll it up to form a short cylinder which will just fit over the equator of your wire globe. Whilst a friend holds a small flame carefully at the centre of the globe, study the shadow of the wires as it can be seen on the outside of the tracing-paper. If you could draw it on the paper and then unfold the cylinder, what kind of map-network would you have?

(*b*) Copy Figs. 50 and 51 on twice the scale.

5. Simple conical projection.—(*a*) Take a circular piece of paper, say 6 in. in diameter, and fold it up, as a filter paper is folded, to form a cone. Gum the folded parts together, so that the cone will preserve its shape. Smear a cricket ball evenly with soft coloured chalk, or with vaseline, and drop the paper cone gently on the ball. After a minute or two remove it without rubbing it about on the ball. Cut the cone open along a fold. What is the shape of the mark on it?

(*b*) Draw a circle of 2 in. radius and mark on its circumference the positions of latitudes 30°, 45° and 60°. Draw a pair of tangents at each latitude and measure the angle at which the tangents of each pair intersect.

(*c*) Take the plasticine model globe used in Expt. 3, p. 61, and place it gently in a glass funnel, with the needle along the centre line of the funnel-neck. Estimate the latitude at which the globe touches the glass. What is the approximate apical angle of the funnel?

(*d*) Make a conical cap of tracing-paper to fit over your wire globe. Cut off the apical part and then, having fitted the truncated cone on the globe to touch it along a parallel of latitude (real or imaginary), hold a small flame at the centre of the model in a darkened room and study the shadow of the wires on the tracing paper.

6. Transference of routes from globe to maps.—On a terrestrial globe stretch a piece of string along the shortest possible line between Freetown (Sierra Leone) and Petropavlovsk (Kamchatka), and mark the line by chalk. Is this line part of a great circle? Select ten points on the line at about equal distances, and observe the latitude and longitude of each. Mark them (or as many as are included) on maps of Africa, of Asia, of the World in Hemispheres, and on Mercator's projection. On each map join the points by a pencil line. In how many cases is the line straight? Similarly transfer from the globe to different maps the shortest course from London to Shanghai, from Yokohama to San Francisco, and from Wellington (New Zealand) to Valdivia (Chile) and compare their appearance in each case.

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* *See also* Cylindrical Equal Area projection.

Principal map projections.—It has been seen that the great drawback of orthographic projection—in which the hemisphere is supposed to be seen by an eye placed at an infinite distance—is the distortion caused by the fact that the central region of the map is on a larger scale than that of the parts nearer the edge. It is natural to suppose that this fault could be rectified by imagining the eye much nearer, and to try the effect of projecting the hemisphere from points at various distances from it. In making such trials it is a help to the imagination to consider the plane of projection as a screen, and the map-network as the shadow of a skeleton hemisphere thrown on the screen by a light placed at the point of projection.

The gnomonic or central projection.—In this case the point of projection is the centre of the earth, while the plane of projection touches the earth but does not cut it. Fig. 47 shows the map-network when the plane touches the earth at the North Pole. It will be seen that from the pole to lat. 50° the distortion is not very pronounced, although it increases towards the edge of the projection ; but the scale rapidly becomes grossly exaggerated as we pass to regions of " lower " latitudes than 50°. As in the polar orthographic projection the meridians are represented by radiating straight lines.

When the plane touches the earth at a point on the equator, the gnomonic projection represents all meridians as parallel straight lines at right angles to the equator. Indeed, *all great circles are represented by straight lines* in this projection. The lines of latitude are more or less curved. For polar regions the gnomonic projection possesses advantages over the orthographic ; it is largely used, however, by American navigators, for charts of the oceans, since a straight line drawn between any two points on a gnomonic map represents an arc of the great circle passing through those places, and therefore shows the *shortest* (though not necessary the best) route between them.

The stereographic projection.—In this method one hemisphere is projected on the tangent (touching) plane from the central point of the surface of the other hemisphere. Fig. 48 shows that, although the scale still increases as the edge of the map is approached, the disproportion is much smaller than in the gnomonic. Also, all parallels of latitude, as well as meridians, on the globe are projected as arcs of circles on the map, and are plotted, therefore, more easily.

A further and important advantage possessed by the stereographic projection is that on the map all intersecting lines are shown cutting each other at the same angles as on the surface of the globe. As a result, perfect local accuracy of shape is obtained. Owing to this last-mentioned property, the stereographic is grouped with Mercator's (p. 75) as an **orthomorphic** (formerly known as *conformable*) projection. For these combined reasons the stereographic projection is to be preferred to others for maps of the polar regions; it is also often

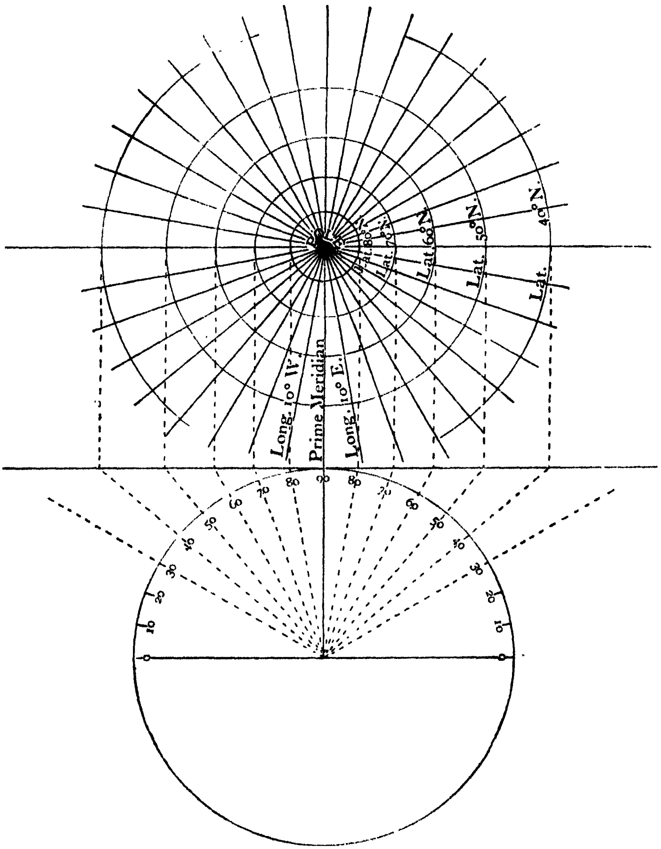

FIG. 47.—Gnomonic or central projection.

used for maps of the hemispheres. It should be remembered, when the latter maps are being used, that the scale of areas at the edge is four times that at the centre.

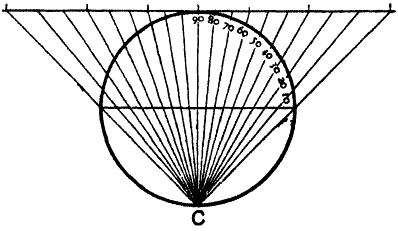

FIG. 48.—Stereographic projection.

The equidistant or globular projection.—We have found that the edge of the map—as compared with the central parts—is on much too small a scale for satisfactory work when the point of projection is at infinity (Fig. 46), and on too large a scale when the point is at the centre of the globe (Fig. 47). Though the scale of the marginal parts is still too large when the point is shifted back to the surface of the globe in the stereographic projection, it has become more nearly accurate. It is, therefore, natural to suppose that the minimum of inaccuracy in projection will be obtained by selecting some point between infinity and the surface of the globe. This point is found at a distance of $\frac{1}{\sqrt{2}}$,* *i.e.* 0·707 . . . times the radius. The distance (*AC*, Fig. 49) may be obtained by bisecting the chord of a quadrant. It will be clear from Fig. 49, which shows the construction, that the projection thus obtained is in almost-exact proportion. In practice the slight discrepancies are ignored, and the lines of latitude (in reality projected as arcs of ellipses) are, like the meridians, represented as the arcs of circles to which they closely approximate. The drawing of a map-network for a hemisphere on the equidistant or globular method is easy. Diameters of the circle at right angles to each other are first drawn, and produced indefinitely. Each radius, as well as each quadrant arc, is trisected if it is desired to represent the network at intervals of 30°, or divided into a greater number of equal parts for

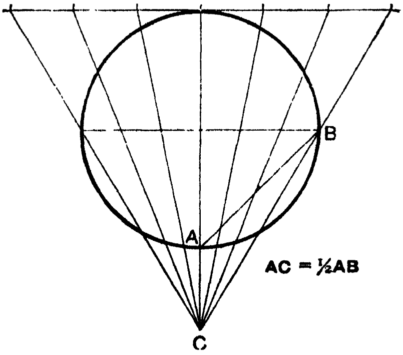

FIG. 49.—Equidistant or globular projection.

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[*] that is, sin 45°.

correspondingly closer meshes. The centres of the circular arcs required all lie on the produced diameters, and are found easily by trial.

The globular projection, or Clarke's (external) projection, is the conventional method of representing hemispheres, or considerable portions of hemispheres such as continents. It is obviously superior to the simple orthographic projection, though not in every respect to the "equal area" modification of the orthographic; while, as compared with the stereographic projection, it has the disadvantage of not being orthomorphic.

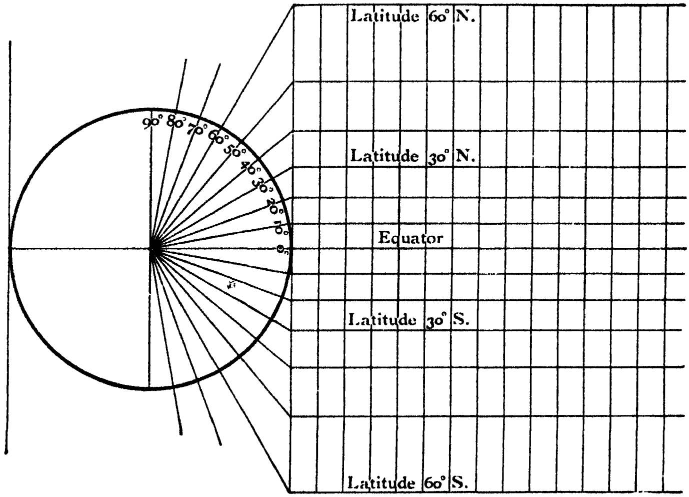

FIG. 50.—Simple cylindrical projection.

Simple cylindrical projections.—In cylindrical projections the network of lines of latitude and longitude is projected, not upon a plane, but upon a cylinder touching the globe along the equator. The cylinder is then spread out flat as a rectangle. If the point of projection be the centre of the globe, the network (Fig. 50) will naturally possess, in general, the qualities of the gnomonic projection (p. 72). The utility of such a projection will therefore be limited to the representation of countries adjoining the equator.

A considerable improvement, however, is obtained **by projecting the network from infinity**, that is, by parallel straight lines at right angles to the axis of the earth (Fig. 51). As before, the meridians (which, of course, on the globe converge to the poles) become equidistant parallel straight lines; but the parallels of latitude now succeed each other at intervals which diminish from the equator to the pole, exactly as they do in the orthographic projection. The result is an "*equal area*" *projection*—that is, one in which areas all over the map are on the same scale—for, as the poles are approached, the scale from east to west becomes enlarged in exactly the same proportion that the scale from north to south becomes reduced. The distortion in respect of shape, however, is consequently enormous.

Mercator's projection.—The geographer Gerard Kramer (better known as Mercator), who lived in the sixteenth century, invented and introduced a modification of the cylindrical method of "projection" which has been used ever since for mariner's charts. We have seen that in a cylindrical projection the meridians, which on the globe converge towards the poles, are mapped as parallel straight lines, so that distances measured from east to west are exaggerated on the map to an extent which increases as the poles are approached. Mercator's improvement consists in also exaggerating distances north and south in the same proportion. The result is that, although the scale of the map increases very much from the equator to the poles, a correct shape is everywhere preserved, and a straight line drawn on the map between two places shows the actual direction (expressed in terms of the compass card) from one to the other. Such a line is called a **rhumb line.** In other words, Mercator's projection is **orthomorphic,** and this is the quality which makes it so valuable in navigation. For other purposes, its chief advantage is that it shows the whole surface of the earth on one map.

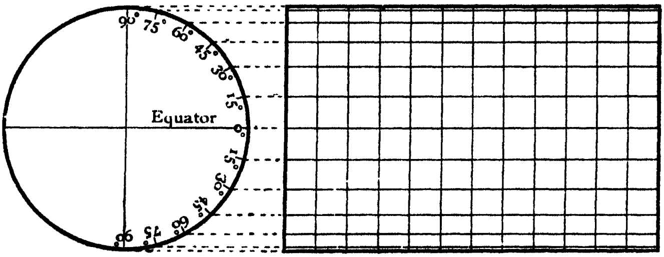

FIG. 51.—Equal-area cylindrical projection.

The principle of Mercator's projection may be illustrated more exactly by the following examples: Measured along the equator, 1° of arc is equal to 69·15 miles, while at latitude 30° the meridians have converged so much that the distance between two meridians 1° apart is only 59·94 miles. A cylindrical projection, however, shows meridians everywhere the same distance apart; that is, the scale in an east-and-westerly direction is here enlarged 69·15/59·94 times. On Mercator's projection, therefore, two parallels of latitude 1° apart would, at this distance from the equator, also be shown 69·15/59·94 times as far apart as a meridian-degree at the equator. At lat. 60° the meridians on a globe are only half as far apart as at the equator. On Mercator's projection, therefore, *all* lengths at this latitude are shown on twice the scale of lengths at the equator, and consequently all *areas* at lat. 60° N. or S. are on four times the equatorial scale. At lat. 70° areas are represented on 8½ times, and at lat. 80° on 33 times the scale of areas at the equator. **Unless this great increase of scale towards the poles be borne in mind constantly, when a map on Mercator's projection is being used, very erroneous impressions of the relative sizes of countries will be obtained.**

Since on the surface of a sphere the shortest line between any two points must form part of a great circle, it follows that the shortest course between two ports *on the same meridian* lies along that meridian, and is therefore represented on Mercator's projection by a straight line. Similarly, the shortest course between any two ports *on the equator* is represented by a straight line on Mercator's projection. All other great circles are, however, represented by curved lines in this projection. It follows that the shortest course between two ports which do not both lie either on the same meridian or on the equator (*e.g.* two ports of lat. 40° S.) would be shown by a curved line on Mercator's projection. It is evident that in "high" latitudes **great circle sailing,** in preference to keeping to the compass direction shown by Mercator's chart, often effects a considerable saving in distance and time to a ship. In general, the advantage of steering by a straight line on a Mercator's chart, and thus of being able to set a course to a definite point of the compass, outweighs the slight lengthening of passage.

The conical projection.—In this class of map-network, which is in general use for all countries not extending through much more than 30° of latitude, the lines of latitude and longitude are supposed to be projected from the centre of the globe on the surface of a cone, fitting on the globe and having its apex on the produced axis of the globe. Two tangents drawn at any given latitude will meet in the axis produced, making an angle with each other which is twice the angle of latitude; and it is obvious that by varying the apical angle, the cone may be made to touch the globe along any desired parallel of latitude except the equator. In the projection, the meridians are represented by straight lines, radiating from the apex of the cone, and the parallels of latitude by arcs of concentric circles of which the centre is the same point.

In practice greater accuracy is secured by supposing the cone to *cut* the earth in two parallels intermediate between the central parallel and the two extreme parallels.

The method of conical projection may be illustrated by a detailed explanation of the **construction of the map-network of a country** say Lower Bengal, including the Ganges delta—Calcutta sheet No. 79 on the one-millionth scale (Fig. 41, facing p. 50).

In this example, the range of longitude is from 88° to 92° E., and the central meridian on the map will therefore be that of 90° E. The latitude extends from 20° N. to 24° N., so that the country is well within the limits (30°) for which a conical projection is suitable. A scale of miles is first drawn, such that the map may nearly fill the space available. The central meridian is drawn, and on it the intersections of the parallels of latitude (20° to 24° inclusive) are set out to scale. On so small a map as Fig. 52 one degree of the meridian may be taken as 68·84 miles.*

The middle parallel is that of 22° N., and we may suppose the cone to cut the globe at 21° N. and 23° N.

Now, along lat. 21°, 1° measures 64·75 miles; while along lat. 23°, 1° measures 60·80 miles. At 21° and 23°, therefore, short straight lines of the respective scale-lengths of 1° are drawn east and west at right angles to the middle meridian. The figure of the map is thus obtained, and the latitudes are determined by sub-dividing the meridian of 90° E. To repeat this strip on both sides and complete the network, the intersections of the lines are carefully marked on tracing-paper, and "pricked off" separately for each meridian. Points of the same latitude may be joined up by straight lines, for on the small scale of this map one degree of a parallel of latitude does not differ appreciably from a straight line; but on a larger scale or with a map extending over a greater number of degrees of longitude, the parallels would be drawn as arcs of circles from the centre found at the intersection of the extreme meridians of the map, produced as shown by the arrows.

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* At lat. 20°, 1° of the meridian measures 68·78 miles.
„ 40°, 1° „ „ „ 69·00 „ (p. 92).

The advantages of the conical projection are that

(1) all meshes between any two given parallels of latitude are of the same shape, and consequently the sides of the map are not distorted as compared with the centre ;

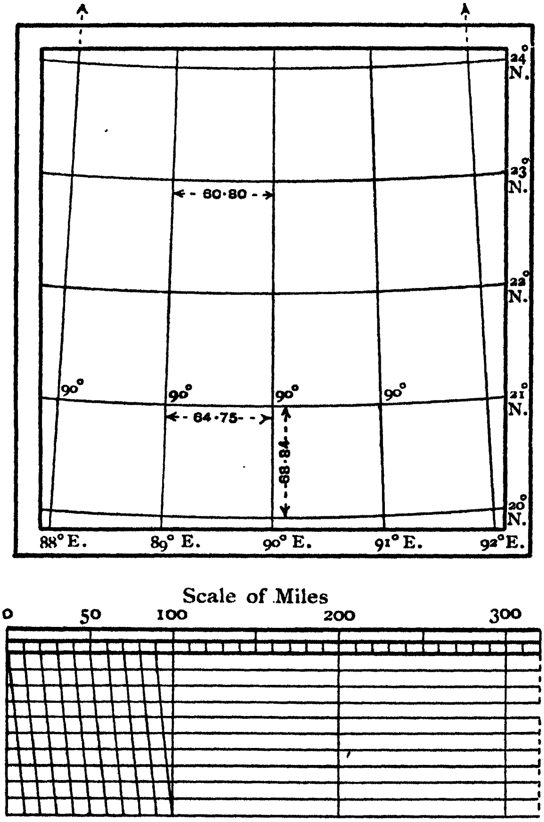

FIG. 52.—Conical projection. Method of drawing the map-network.

(2) within the limits of latitude—about 30°—to which a map on this projection is generally restricted, there is no appreciable change in the shape of the meshes even from north to south, especially if the cone is supposed to cut the globe along two parallels ; and

(3) it is possible to make all the meridians, as well as the two selected parallels, true to scale.

Survey of India maps.—The modern maps, since 1905, of one inch, half-inch, quarter-inch, and the one-millionth, drawn on the polyconic projection, are almost free from scale error or distortion, but in this projection a large number of maps cannot be joined to form a composite map without slight gaps appearing at the edges. Modified secant conical projection, covering the whole of India, has been used for smaller scale maps, but in these some distortion is inevitable, and the scale errors in places amount to 2 per cent.

The maps of the Survey of India are drawn on the pseudoconical projection, known as **Polyconic** projection, not because there is any special merit in the method of using a series of cones for successive latitudes but because it is simpler for tabulation.*

It is to be remembered that the simple conical projection is not orthorhombic, *i.e.* that the meridians and parallels should everywhere cut at right angles, and at any point the scale along the intersecting parallel should be the same as the scale along the intersecting meridian, so that in any small area a map on the projection should give an undistorted picture of the earth's surface.

Equal-area projections.—Besides the equal-area modifications of the cylindrical (Fig. 51) and orthographic (p. 68) projections already described in this chapter, other and better equal-area networks are in common use. One of the most generally useful—because it shows the whole earth on one map, and with relatively little distortion of the shapes of countries—is known as the **elliptical equal-area network** and is drawn on Mollweide's equal area projection (Fig. 53). In shape the map is an ellipse, the major axis of which, representing

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* The projection used for the Atlas of India Maps by John Walker, Geographer to the India Office, between 1826-68, and subsequently used for the uncompleted sheets, is thus described by the Surveyor-General, J. T. Walker: "This is one of the numerous modifications of the conical development, it represents the parallels of latitude by concentric arcs, but the meridians by arcs concave to the central meridian, in this case 76° 30′ E., and not by straight lines as is the case in true conical projection. A cone is assumed to roll over the spheroid tangentially to an adopted parallel of latitude (24° 30′ N.), the distance from the vertex of the cone to this parallel (= normal × cotan. longitude—nearly 8,710 miles) is the radius of the projection of the parallel, and may be considered as the fundamental radius of the projection for the radii for all other parallels are determined by adding to or subtracting from it the distance—roughly 68·84 miles—between those parallels and the central parallel. The angle subtended at the vertex of the cone by a longitude arc of 1° in length is called the 'angle of the projection' for the parallel of latitude to which the arc appertains. As this angle varies with the latitude, its value is computed for each parallel."

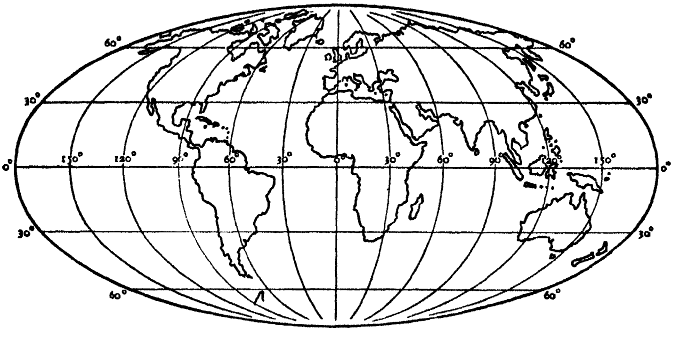
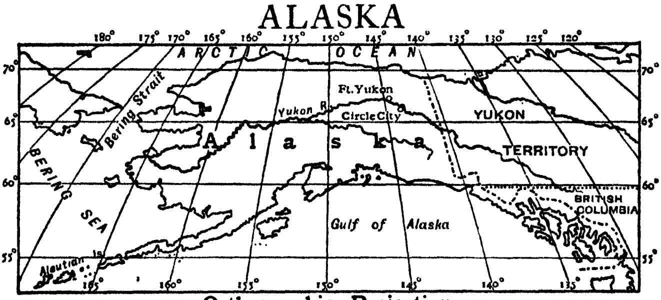
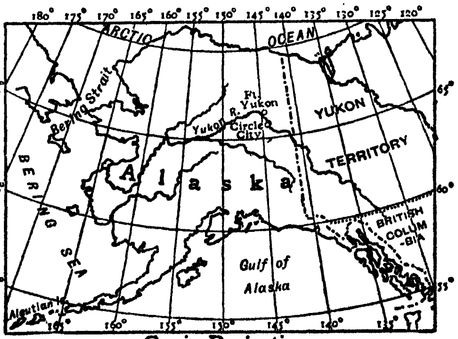


FIG. 53.



Orthographic Projection



Conic Projection

FIG. 54.—Alaska on two different projections.

the equator, is twice the length of the minor axis, which represents the central (usually the prime) meridian. For a network of 10° mesh the central meridian is divided into 18 equal parts, and the equator into 36 equal parts. The parallels of latitude are straight lines parallel to the equator, and the meridians are ellipses drawn through the poles and the divisions of the equator.

Equal-area networks are naturally most useful for maps intended to show the relative *extent* of areas displaying some specific character, *e.g.* foreign possessions, distribution of races, crops, minerals, density of population, rainfall, etc. It is plain that such maps ought to be provided with a scale of areas, stating the number of square miles represented by, say, one square inch, instead of a linear scale, which at best can be only approximate.

Fig. 54 shows in the case of Alaska—selected on account of its high latitude—how the shape of a country may vary when drawn on different projections. The choice of a projection depends on the function which the map is intended to fill. If the map is for statistical purposes, to show areas, density of population, rainfall, etc., an equal area projection should be used. At sea Mercator's is practically the only projection used, except when it is desired to determine graphically great circle courses in great oceans or for long distance aerial flights. In these cases gnomonic or central projection is generally used. For conveying general ideas of the shape and distribution of the surface features of continents or of a hemisphere, the external (Clarke's) projection is a good one. For exhibiting the progress of polar exploration the polar equidistant projection should be employed. For special maps for general use on scales of one millionth and smaller, such as those facing pages 50 and 39, and for a series of which the sheets fit together, the conical, with rectified meridian and two standard parallels, is an excellent projection. For topographical maps of scale not less than $\frac{1}{500000}$ and sheets independent (*i.e.* not fitting together) the polyconic projection is very convenient.

Photographic aerial surveys.—Those who have not yet made a study of aerial survey methods may be interested in a little elementary photographic geometry and its application to map making.

A map may be described as an orthogonal projection of the ground on to a horizontal plane, reduced to some convenient scale, and a photograph as a conical projection of the ground on to the focal plane of the camera. If the focal plane is horizontal at the instant of exposure, and the ground being photographed is perfectly level, the two projections are exactly similar and the photograph is indeed a map. Unfortunately, those conditions which are illustrated in Fig.

116 are extremely rarely encountered, and the photographs usually need correcting for various distortions.

Height distortions.—On the ground a chimney is shown, on the map as a small circle. The photograph, however, shows the chimney in perspective. This is an illustration of what is known as height distortion.

Fig. 55 shows the conditions when the camera is tilted. On the ground is represented a level football field. Since the field is level it may also be regarded as a map, scale 1 : 1. Vertically underneath the lens at a point *P* known as the " Plumb Point ", a man is holding an upright post, which is depicted as the point *p* on the photograph.

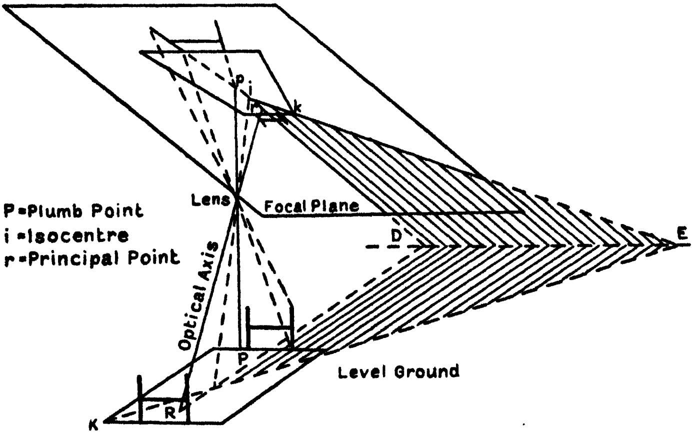


FIG. 55.

There is therefore no height distortion at the " Plumb Point ". The map and photograph positions of the top of the goal posts, however, are very different. On the photograph the posts appear to radiate from the Plumb Point *p*. Thus an important geometrical fact is illustrated.

Height distortion is radial from the Plumb Point.

Tilt distortions.—No way has yet been discovered of ensuring that the camera is perfectly level during an exposure, and it is, therefore, necessary to consider distortions, known as tilt distortions due to the focal plane not being horizontal.

In Fig. 55 the " Principal Point " *r* is the foot of the perpendicular from the lens on to the focal plane. The projection of this point on the ground is *R*. The Principal Point being integral with the camera is automatically marked on every survey photograph. Imagine the focal plane produced to meet the plane of the level ground in a line *DE*. Produce *RP* on the ground and *pr* on the focal plane. They will both meet *DE* in a common point *D*. Next bisect the angle at the lens subtended by *PR*. The bisector will cut the ground in *I* and the focal plane in a point *i*, known as the " Isocentre ". Take any point on the ground such as the corner of the football field *K*. Produce *KI* and *ik*. They will meet *DE* in *E*. A little consideration will show that in the two shaded triangles :

$Di = DI$.
The side *DE* is common.
The angles at *D* are right angles.

Thus the two triangles are congruent and the angles at *I* and *i* are equal. Similarly it can be shown that any angles on the level ground at *I* will be accurately reproduced at the isocentre *i*, on the photograph. This illustrates another geometrical fact :

Tilt distortion is radial from the Isocentre.

Both the important distortions have now been considered and found to be radial ; one from the Plumb Point, and one from the Isocentre.

When flying for air survey every effort is made to keep the camera as level as possible. With a specially trained pilot it is possible to keep within 2° of the horizontal. Should the camera happen to be truly level during an exposure, the Principal axis will coincide with the Plumb line ; and thus Plumb Point, Principal Point and Isocentre will be coincident and all distortions will be height distortion radial from the Principal Point. If, however, the camera is only slightly tilted these three points will be very near together. They will indeed be so near together that no very large errors will be made if it is assumed that all distortions are radial from the Principal Point. It is worth while to note here that other distortions, not usually large enough to matter, such as lens distortions, and those due to atmospheric refraction, may also generally be considered as radial from the Principal Point.

In order to make a map from the photographs, it is necessary to remove both these important distortions. If the country is perfectly flat such as the Irawadi delta in Burma, or the great plains of India and China, there will be no appreciable height distortion, and the photographs can be corrected optically by tilting the easel of a specially designed enlarger. When there is height distortion they must be treated in a different way. The usual method of plotting from air photographs at scales of from two to six inches to the mile is known as the radial method.

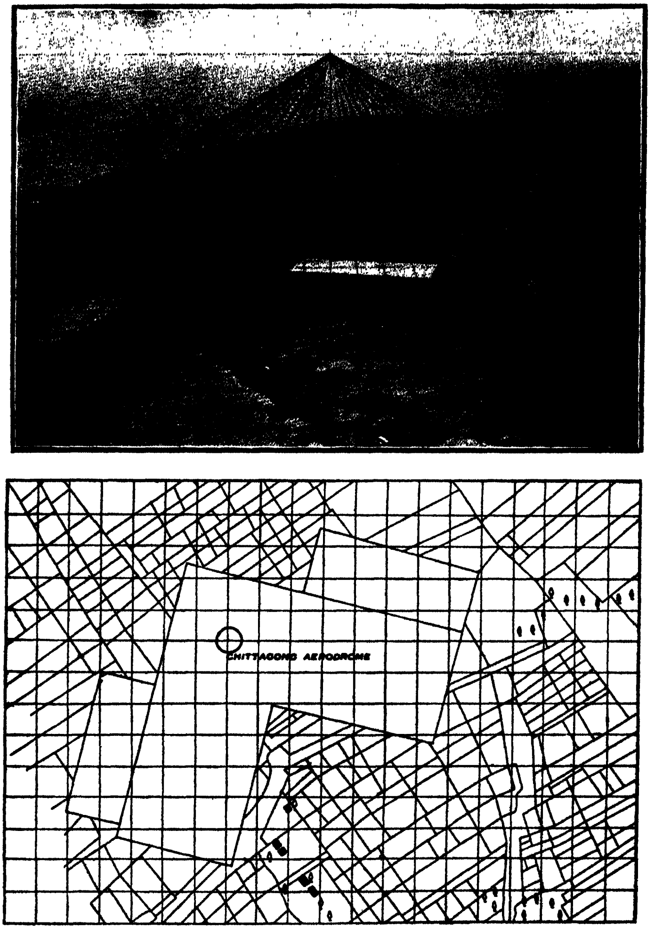


FIG. 56A (TOP) AND 56B.—(With the permission of the Indian Air Survey and Transport Ltd., Dum Dum, Calcutta.)

The radial method of mapping.—The assumption that all distortion on the photograph is radial from the Principal Point, or that all directions from the Principal Point are true directions (which is the same thing) is the only assumption that is made in mapping from photographs by this method. The photographs are exposed in strips, so that each photograph overlaps its neighbour at least 60 per cent. in the direction of flight and usually about 20 per cent. laterally. They are then developed and points of details are chosen which appear in the common overlap of every three neighbouring photographs. Neighbouring Principal Points are also identified and all points are inked up and joined to the Principal Point of the photograph on which they appear.

All angles can now be measured at the Principal Points, and give the same information that a man with a theodolite would give, were he to visit each Principal Point on the ground, and observe rounds of angles to the chosen points.

A chain of triangles is then built up with the Principal Points, and the chosen points. Since all angles at Principal Points can be measured on the photographs, the angles at the chosen points can be deduced. Thus we know all the angles in the figure. A convenient length is chosen for the distance between two Principal Points (*AB*) and the chain of triangles is either computed by trigonometry or constructed graphically, distributing any small errors should they appear. The result is a map grid consisting of a chain of triangles to a scale which depends on the length assigned to *AB* and is quite independent of the scales of the photographs. The detail is interpolated into the grid and the scale value determined by comparing a measurement on the map with a direct measurement on the ground. The map is then enlarged or reduced to the scale required.

" For small scale work when a high degree of accuracy is not required, economical maps can be made by transferring the detail from a perspective grid superimposed on an oblique photograph (Fig. 56A) to a rectangular grid ruled on the compilation (Fig. 56B). An oblique photograph covers a very much larger area than a vertical photograph, but the detail in the extreme distance is too small to be of much use for mapping." (Figs. 55, 56A and B, and description were very kindly supplied by Indian Air Survey and Transport Ltd.)

EXERCISES ON CHAPTER III

1. What is meant by Latitude and Longitude? Is there any difference in the lengths of degrees of Latitude and Longitude? Explain.

2. Explain how to draw the meridians and parallels of latitude for a map of the hemisphere on the orthographic projection.

3. What are the special advantages and disadvantages of a map on an " equal area " projection? Mention any purposes for which you would prefer to use such a map.

4. State exactly what is meant by the term map-projection, and explain (*a*) how the chief difficulty of map-making arises, and (*b*) the different qualities that are possessed by different projections.

5. Explain the method on which a Mercator map is made, and state the advantages and disadvantages of this projection.

6. Give the construction of a network of latitudes and longitudes which will show areas truly.

What are the advantages and disadvantages of a map on such a network? And for what purposes should you select it?

7. What is meant by Mercator's Projection? Explain its principle, illustrating your answer with diagrams. Point out the chief errors of this system of projection and state for what purposes it is chiefly used and why.

8. For what special properties are the following projections respectively useful: Gnomonic (central), stereographic, globular, conical, Mercator's?

9. Describe three varieties of cylindrical projection, and in each case mention the most important property.

10. Which do you consider the best projections to use (*a*) for showing the size of the British Empire, (*b*) for laying down a route for crossing the Atlantic by airship, (*c*) for comparing the directions of mountain-chains or of coast lines, (*d*) for comparing the areas of the African and North American lakes? Give your reason in each case.

11. What is the difference between a " great circle " and a " small circle " on the globe?

Explain why the shortest distance between two places on the same meridian is along that meridian, but the shortest distance between two places on the same parallel of latitude is not, in general, along that parallel.

12. Compare the special uses, for purposes of navigation, of the gnomonic and Mercator's projections.

13. What are the advantages of orthomorphic map networks? Give a general description of two such networks.

14. What is meant by " great-circle sailing "? In what circumstances is it advantageous?

CHAPTER IV

THE EARTH AS A PLANET

9. THE SHAPE OF THE EARTH

1. The earth's shadow.—Look in any good almanac of the current year for the date and time of the next eclipse of the moon ; and, if it is visible where you are, take the opportunity of studying the earth's shadow which is then thrown on the moon.

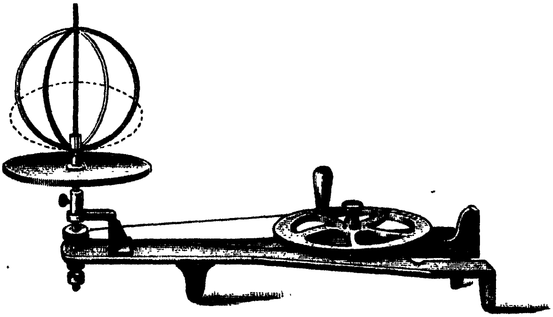


FIG. 57.—Apparatus to show the flattening produced by spinning a flexible steel hoop.

2. Other shadows.—Project, by means of a candle, say, 10 ft. from a white screen, the shadow of (*a*) a ball, (*b*) an egg, (*c*) a circular disc, placed in turn on the perpendicular line from candle to screen. Study the form of the shadows as the objects are rotated. Of how many of the objects is the shadow always circular?

3. The horizon. (*Outdoor work.*)—Observe the curvature of the horizon of any large and flat expanse, *e.g.* the surface of the sea or a wide plain. What angle with the horizontal is made by a telescope pointing to an object on the observer's horizon? Is this angle the same whether the observer is standing on the shore or on a high cliff? Can the same point be on the horizon of two persons at different heights? How does the distance of the horizon vary as you respectively (*a*) lie, (*b*) sit, (*c*) stand on the sea shore, and (*d*) climb a cliff or hill? Why are lighthouses placed on elevated positions rather than on the sea level? Which part of a ship approaching port comes into view first? What prevents the rest of the ship from being seen so soon? What would be the possible shapes of the visible limit (horizon) of (*a*) a cricket ball, (*b*) an egg, to an insect walking over its surface?

4. Oblate spheroid.—(*a*) Procure a circular hoop of thin steel, and support it upon an axis attached to a whirling-table as shown in Fig. 57. Set it spinning by turning the handle of the whirling-table. Notice that the hoop assumes a more flattened form. The flattening is increased as the rate of spinning is made greater.

(*b*) Mix rectified spirits and water until a few drops of oil just float on the mixture when it is quite cool. Pour fresh oil, by means of a pipette, into the middle of the mixture, and notice that a spherical globe of oil may thus be formed. By means of a glass rod set the liquid spinning, and observe that the globe of oil assumes a flattened form when it is made to rotate.

5. The altitude of the polar star. (*Outdoor work.*)—Obtain two thin rods of wood about a foot in length. Place the two together and push a pin through them both near one end, so as to hold them like the legs of a pair of compasses. Using either a rough arrangement of this kind, a clinometer (p. 29), or a better instrument if one is available, estimate the angle which the direction of the pole star (p. 90) makes with the horizon. This angle is equal to the latitude of your position (Fig. 60).

The form of the earth.—The history of the different ideas which men have had respecting the shape of the earth forms an interesting example of the change in attitude of man's mind towards all questions as his knowledge increases. In early times the most fanciful notions respecting the earth's form found ready acceptance, and even in recent time so-called proofs of the globular shape of the earth were accepted which were really not proofs at all.* At present we believe that the earth is more or less spherical, that is, more or less round like a ball, for such reasons as the following :

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* The early Greek astronomers ascertained that the earth is a sphere. Homer (850 B.C.) wrote of the sea surface being convex and Aristotle (320 B.C.) gave reasons in support of the spherical form. Eratosthenes even made a calculation of the size of the earth from the distance between Aswan (Assouan) and Alexandria and their latitudes.

(1) *The shape of the earth's shadow cast upon the moon during lunar eclipses is always circular.* We know from geometry and experiment that the only solid which always gives a circular shadow, wherever the light which throws it is situated, is the sphere. Because the outline of the earth's shadow is always circular (Fig. 49), whatever may be its position with regard to the sun, we feel justified in asserting that the earth must be a more or less perfect sphere. From other considerations we believe that the sphere is not perfect, but flattened towards the two poles.

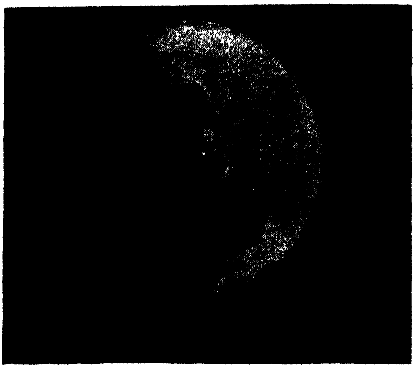

FIG. 58.—Photograph of an eclipse of the moon showing the curved form of the earth's shadow.

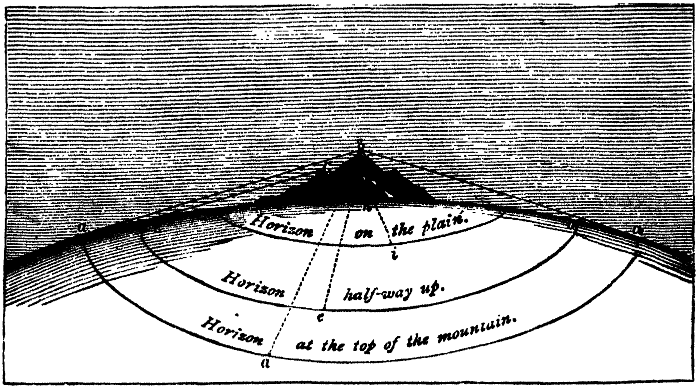

FIG. 59.—The horizon is always circular.

(2) *The dip of the horizon to right and left is everywhere the same. In consequence it appears circular to an observer raised above the*

earth's surface. It is characteristic of a sphere that, from whatever point it is viewed, it always appears circular ; and since the horizon, that is, the line where earth and sky appear to meet, bounds a circular space at whatever altitude the observer is situated, and wherever he may chance to be upon the earth's surface, it is evident that this reason alone gives us strong grounds for asserting that the earth is round like a globe.

(3) *The times of rising, southing, and setting of the sun and stars are different at places situated on different meridians.* If the earth were flat, as soon as the sun appeared above its edge it would be visible throughout the earth's surface. But this is by no means the case. Similarly, the sun—being at a very great distance—would "south", *i.e.* attain its highest position in the sky, at an instant which would be the same for all parts of a flat earth. This, too, is just as far from the truth. When it is noon at Greenwich it is 7 a.m. at New York, and 3 p.m. at Aden, 4.30 p.m. in Kabul and 6 p.m. at Calcutta,* so the sun may be rising at the former place and setting at the latter. This reason should be reverted to after the section on longitude and time (p. 106) has been read.

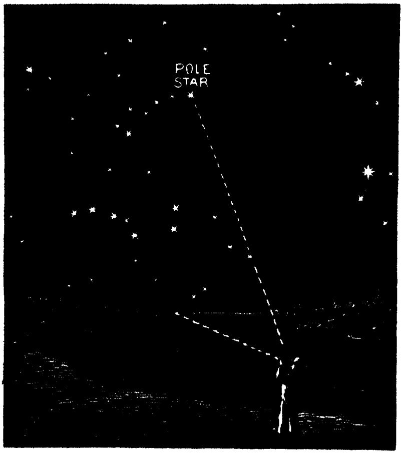

FIG. 60.—The altitude of the pole star is approximately equal to the latitude of the place of observation.

(4) *The altitude of the pole star regularly increases as the observer travels from the equator to the poles.* If the surface of the earth were horizontal the altitude of the pole star—the start being at "infinite" distance—would be the same from whatever place it was viewed. But observation shows beyond a doubt that as we travel northwards the altitude gets greater and greater until at the north pole the star would be exactly overhead, or its altitude would be 90°. If we travel in the reverse direction, the reverse changes occur ; the altitude of the pole star diminishes from 90° at the pole until at the equator the pole star appears in the horizon, or its altitude is 0°.

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* Local Calcutta time is 5 h. 53 m. 20·8 s. as against Indian Standard time, 5 h. 30 m., reckoned from 82° 30′ E.

To bring about these changes in the altitude of the pole star, it is clear that the observer must himself have described an angle of 90°, for the change in the observer's position could have no actual effect upon that of the pole star. Hence in travelling from the pole to the equator the observer describes one-quarter of a circle, and if he went right round the earth he would cover $4 \times 90° = 360°$, or a complete circle. A little thought will show, also, that the altitude of the pole star must always be equal to the latitude of the observer.

Measurement of the earth's circumference.—The earth is, for the reasons given, considered to be spherical in form,* and it will be desirable now to consider how the length of a line round the earth has been determined. A line encircling the earth, and passing round it in such a way that the plane containing it passes through the centre, is called a great circle, or circumference of the sphere. We can ascertain the length of such a circle from the following considerations.

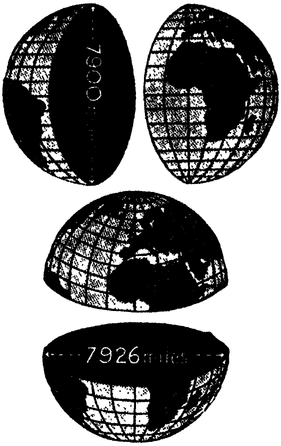

FIG. 61.—Polar and equatorial diameters of the earth.

From the last of the reasons given above for believing the earth to be spherical, we know that to make a difference of one degree in the altitude of the pole star we must travel through an angle of one degree measured along a meridian of the earth. The plan to be adopted, therefore, is to travel northwards or southwards for such a distance † along a meridian as to cause a difference of one degree in the altitude of the pole-star. When this has been done $\frac{1}{360}$ part of the circle round the earth has been traversed, and consequently to determine the circumference it is merely necessary to multiply the distance travelled by 360. It has been found that the distance to be travelled to bring about such an alteration of one degree in the pole star's altitude is not always the same. As the poles are approached this distance becomes greater. No difference whatever in altitude would be produced in a flat earth, and it may be argued that since for a given journey the difference in altitude produced is less towards the poles we must be travelling on a flatter earth, *i.e.* the earth is flattened somewhat near the poles. These varying lengths are, of course, the lengths of degrees of latitude along different portions of meridians.

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* As already stated, the Greeks considered the earth to be a sphere. Sir Isaac Newton recognised the flattening of the earth at the poles, causing the shape to be a spheroid. Afterwards, computed observations by Clarke led him to believe that the earth had the shape of a tri-axial ellipsoid, and now we consider that the best term to use for the figure of the earth is the *geoid*.

† Measured by triangulation (p. 42). The Great Arc of India, which has been measured by triangulation from Cape Comorin, roughly 8° N, to near Dehra Dun, nearly 30° N., covers a meridional arc of over 22°.

Variation of degrees of latitude.—In travelling from the equator to the poles, then, there is a gradual increase in the length of a degree of latitude. The amount of such difference will be seen from the following table :

LATITUDE	Distance travelled to bring about difference of 1° in altitude of pole star = length of 1° of latitude.
Equator	68·69 miles
10°	68·70 ,,
20°	68·77 ,,
40°	69·00 ,,
60°	69·21 ,,
80°	69·38 ,,
Pole	69·39 ,,

By taking an average value of the lengths of these degrees of latitude, say 69 miles, and multiplying it by 360, we obtain 24,840 miles as the length of 360 degrees, or a complete circle round the earth ; and if this is divided by $3\frac{1}{7}$ (the ratio of the circumference of a circle to the diameter) the diameter is found to be 7918 miles.

Exact shape of the earth.—A globular body flattened towards two points, situated as far as possible away from each other, is called an **oblate spheroid.** The points of flattening are called the *poles*, and the line joining the poles is known as the *axis*.

It is usual to describe the earth as having the form of an oblate spheroid, but this is not strictly true. It is now admitted by all physical geographers that the earth is very slightly flattened at the equator as well as at the poles ; that is to say, a belt placed round the earth at the equator would not be a circle, but very slightly elliptical in shape. Moreover, recent polar explorations have shown that though the crust of the earth in north polar regions is greatly below sea level, the reverse is the case in south polar regions, which consist of high and mountainous land, the mean height of the Antarctic continent being probably about 2000 metres. Grossly exaggerating, we may say that the earth is pear-shaped, with the stalk in the south ; but of course the difference between the level of the north and south polar regions is relatively insignificant. No common object can really represent the shape of the earth, nor can a geometrical term express it. Perhaps the best word to use is **geoid**,* which signifies merely earth-shaped.

A problem of some importance is that involved in the question, " What are the dimensions of the **geoid** and its departure from a **spheroid**? " Those dimensions, as ascertained by triangulation and by pendulum experiments, while permitting our surveyors to fix the map of India on to the figure of the earth, have not provided a solution for the irregularities, both in the form and density of the earth's crust, and the local attraction exerted by that crust, at various points, on a weight suspended from a thread and known as a " plumb line ". The plumb line defines the vertical, *i.e.* it hangs at right angles to a water surface. If a plumb line is deflected by the attraction of mountain masses, the vertical and the normal are not coincident and the water surface is tilted with respect to the mean figure. The bubble in the level of surveying telescopes is affected in the same way as a water surface and may thus be tilted as regards the true horizon. As far back as 1835 Sir George Everest had foreseen that the " pull " of the Himalayas would affect the problem, and it was found that the deflection of the plumb line at the foot of the Himalayas, at Dehra Dun, is 37 seconds from the vertical; at Kaliana, 50 miles away, it is only 7 seconds and at a distance of 100 miles it disappears.

The question was referred to the mathematician Archdeacon Pratt of Calcutta in 1852 by Col. Waugh, the Surveyor-General, and it was shown by Pratt that the deflection at Kaliana by mountain attraction only should have been 28 seconds and not 7 seconds as found, so that some underground cause was compensating the "pull" of the Himalayas. Subsequently, in 1887, when observations were extended to over 100 miles, to Agra and Benares, the plumb line was found to be deflected to the south—away from the mountains. And again, later, in 1901, Col. Sir Sydney Burrard found that between the Nerbada and Godavari valleys the plumb line deflections were to the north, although no visible mountains were there, and he concluded that there must be a " Hidden Range " buried in the earth's crust south of the Gangetic plains. His views as to a belt of high density—the Hidden Range—are supported by Col. Glennie's gravity investigations. Discussing such data Dr. H. Jeffreys says " It is found in most cases that on the whole the lack of mass below mountains and excess below oceans are about equal to balance the excess and deficit of mass due to visible inequalities. We call the relation **isostasy**, and the subterranean variations of mass **compensation**. (" Earthquakes and Mountains ", 1935, p. 74.)

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* The geoid may be defined as the figure of the earth enclosed by the surface of the sea, that is, the surface of a spheroid disfigured by protuberances and hollows.

It has been said that a careful examination of terrestrial ridges, elevated areas and depressions shows that the earth's form approaches that of a tetrahedron, which is a solid body having four faces, six edges, and four corners.* The earth is not, of course, tetrahedral in the ordinary sense of the word, but when the distribution of land and water and the courses of the main watersheds and mountain chains are examined critically, ridges are found in the approximate positions of the edges of a tetrahedron and slight flattenings between them suggesting the faces of a tetrahedron. There is no actual evidence available that the earth must tend towards this shape, but it is claimed that a globe of plastic material surrounded by a hard crust gradually assumes the form of a tetrahedron as it cools, and the earth appears to be an example of this fact on a large scale.

The following passage, however, shows how slight is the departure of the earth's shape from that of a sphere. " As to the smoothness and roundness of the earth, if represented by an 18-inch globe the difference between the greatest and least diameters would be only about $\frac{1}{16}$ of an inch. The highest mountains would project only about $\frac{1}{75}$ of an inch, and the average elevation of continents and depths of the ocean would be hardly greater on that scale than the thickness of a film of varnish. Relatively the earth is much smoother and rounder than most of the balls in a bowling-alley."†

* Elie de Beaumont, in 1852, had speculated with the idea that the shape of the earth was a sphere built up on a rhombic-dodecahedron. Lowthian Green, in 1875, suggested the geomorphology which bases a sphere on a regular tetrahedron to give the form of the earth. Both these theories exaggerate the influence of any shape other than a spheroid. J. W. Gregory, " The Plan of the Earth and its Causes."

† Young's " Manual of Astronomy " (Boston and London: Ginn & Co.).

10. THE ROTATION OF THE EARTH

1. **Model of Foucault's pendulum.**—Swing a heavy ball suspended freely by a fine wire from a point fixed to a support which rests on a board that can be moved round as required. Let a stiff horse hair attached to the ball just touch the board, and on the board place a very smooth piece of paper which has been held close over a piece of burning camphor until coated all over with black. Cause the pendulum to swing, by moving it to an angle with the vertical by a piece of thread and then cutting the thread with scissors. Slowly rotate the board round a centre. It will be found that the ball swings in the same direction, as regards the room, as that in which it originally started, and regardless of the motion of the board.

2. **The apparent diurnal motion of stars.**—(*a*) On a clear night fix on any bright star (i) when facing north, (ii) when facing south, and note its position in the heavens. In each case, observe the star again an hour later. Is it in the same position as before? If not, in what direction has it moved in the meantime?

(*b*) Take up a position to the south of a convenient vertical line, *e.g.* a telegraph post or the corner of a building. You can do this by sighting the pole star against the line. Observe that a star above the pole star attains its highest point in the sky as it passes behind this vertical line from east to west, whereas a star below the pole star is at its lowest point and passes from west to east. Note by your watch the time of passing the line, and see if the same star passes the same point at the same time on the following night. If you can find a wall, the face of which lies exactly north and south, you can similarly, from a position to the north of it, observe when stars are due south and at their highest points.

(*c*) Focus a camera at the pole star, put in a sensitised plate, and expose it for a couple of hours. Then take out the plate and develop it.

3. **Angular measurement applied to the sky.**—(*a*) Using an arrangement such as is described in Expt. 5, Sec. 9, or a better instrument if one is available, measure some angular distances between stars. For instance, point one of the legs of the instrument to the pole star, and the other to the nearer of the pointers; then place the legs so that their junction lies at the centre of a circle divided into degrees, and determine the angle between them.

(*b*) In the same way measure other angular distances, such as those between the following stars (Fig. 4): (i) the two extreme stars in the Plough; (ii) the pointer (α) nearest the pole star, and the star marked η in Ursa Major; (iii) the pole star, and ϵ in Cassiopeia; (iv) Capella and the pole star. Find out whether the angular distance between two selected stars varies at different times, or is always the same.

4. Circumpolar stars.—On a clear night open the jointed rods to an angle equal to the latitude of your position, and observe which stars are included within this angular distance from the pole star. These are the stars which are always visible from your latitude when the sky is clear. Other stars " set " on the western horizon once a day, and are out of view until they " rise " again on the eastern horizon.

5. Experimental illustration of rotation.—Place a small ball or globe upon a table. Stick a long pin into the globe anywhere except at a pole. Rotate the globe on its axis so that the northern hemisphere moves in the opposite way to the motion of the hands of a watch. Notice that the pin is turned in succession towards different objects upon the walls, floor and ceiling of the room, which may be regarded as stars in the heavens. If the globe rotated at a uniform rate, the period of rotation could be determined by observing the interval between two successive appearances of any one star in the same position.

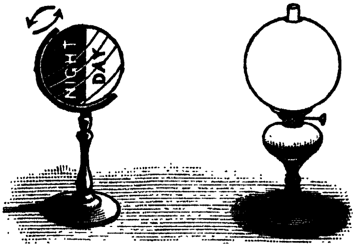

FIG. 62.—Experiment to explain the cause of day and night.

6. Day and night.—Light a lamp to represent the sun, and place the globe near it. One half of the globe is illuminated, and the other hemisphere is in darkness. Rotate the globe as before ; different parts are thus successively turned into the light and darkness. The rising and setting of the sun can thus be shown to be explained by the rotation of the earth on its axis from west to east.

Rotation of the earth on its axis.—The earth spins on its axis in a manner which resembles the spinning of the globe in Expt. 5, sec. **10.** This spinning motion constitutes **rotation.** In the case of a globe rotating upon a needle without thickness as axis, it is apparent that the axis itself is free from any spinning motion, while the parts of the globe farthest away from the needle move through the greatest distance in a given time, or have the highest velocity. Similarly with the earth, the poles are at rest, while places on the equator are carried through a distance of about 25,000 miles in the time of one rotation, which is twenty-four hours ; that is, they have a velocity of over 1000 miles an hour.

The rotation of the earth causes day and night.—The sun and the earth are bodies in space ; the sun is luminous, while the earth is a dark body with no light of its own. The sun sheds its light in every direction, and lights up that half of the earth which is nearer to it, the remote half meanwhile being in the dark (Fig. 62). Were the earth at rest this would be so always ; one-half would be illuminated always or enjoy the brightness of day, the other would be in the perpetual darkness of night. But since the earth is rotating, new parts of our planet are being brought constantly " out of darkness into light ". The night is followed regularly by the day, and as the spinning carries any place round, it is in due course taken out of the sunshine into the shadow of evening again.

Proof of the earth's rotation.—The apparent daily motions of sun and stars are a direct consequence of the earth's rotation, but a moment's thought is enough to show that exactly the same appearances would be observed were the earth, as was originally thought, the rigid centre of a moving universe. Thus it is impossible to decide from observations of the stars alone whether it is the earth or the stars which rotate, just as when two railway trains are side by side it is very difficult for a passenger in one train, when observing the other, to decide which train is in motion. If the earth were fixed, while the heavens moved round it as a centre once in twenty-four hours, we should have just the same alternation of day and night, and the identical succession of rising, southing (p. 90) and setting of the celestial bodies. We should be faced with the problem of the sun and stars travelling round the earth at inconceivable velocities—for since the velocity of a point on the earth's equator is 1000 miles an hour, the sun, at a radius of 24,000 times the earth's radius, would be travelling at a speed of 24,000,000 miles an hour. The movements of the spots on the sun across its disc afford evidence of the sun's rotation on its own axis, and, judging from the fact that the planet Mars is known to rotate in a period of nearly 24 hours, we have a strong probability of the earth's rotation once in a sidereal day. But, fortunately, direct proofs are to hand.

The experimental proofs of the earth's rotation may be summarised as follows :

1. By experiments with Foucault's pendulum.
2. By experiments with Foucault's gyroscope.

3. By the observation of bodies falling from a great height towards the earth. Such falling bodies are deviated towards the east.

4. By experiments on the deviation of projectiles. Since the earth rotates from west to east, the target will be carried eastwards and the projectile will appear to deviate to the west except at the equator. It is necessary to allow for this deviation in gunnery.

5. By observations of trade winds and ocean currents. The currents of air travelling towards the hotter parts of the earth at the equator, as in the case of projectiles, undergo a deflection to the right in the northern hemisphere and towards the left in the southern hemisphere. In a similar manner, the earth's rotation causes a deviation of the ocean currents.

6. By the effects of the earth's rotation (centrifugal force) on the weight of a body in different latitudes—there is loss of weight from the poles to the equator where the rotation is greatest.

7. By the figure of the earth, which being an oblate spheroid is a sphere of rotation.

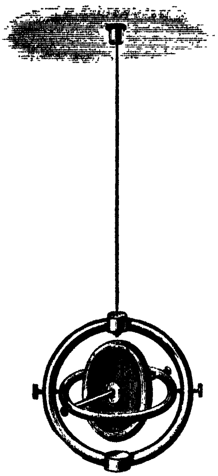

Fig. 63.—Foucault's gyroscope. For explanation, see text.

Foucault's pendulum.—Newton's **First Law of Motion** asserts that *every body continues in its state of rest or of uniform motion in a straight line until it is compelled by impressed force to change that state.* This statement of one of the properties of matter is admitted on all hands to be true, and in 1851 M. Foucault made use of the property to demonstrate the earth's rotation. If a heavy pendulum is set oscillating, it resists any attempt to force it out of the plane in which it is swinging. Expt. 1, Sec. 10, shows this prettily on a small scale. Foucault, making use of the fact which the experiment illustrates, suspended a heavy iron ball, by means of a long, thin wire, from the roof of the Panthéon in Paris. This pendulum was pulled out of the vertical and held on one side by a thread attached to the wall. The pendulum was then allowed to swing to and fro over a circle of sand on the floor. The experiment can, however, be done satisfactorily if a table on which marks have been drawn be substituted.

The pendulum is set swinging by burning the thread. As time goes on the suspended weight seems to pass along a different line on the table from that originally traversed, and it is clear that one of two things must have happened—either the plane of the pendulum's oscillation must have altered, or else the table must have turned round. But Expt. 1, Sec. 10, shows that the former alternative is impossible, and we are forced to the conclusion that the table, and therefore the earth of which it is a part, gradually turn round. If the experiment were performed at either of the poles the table would turn completely round once in twenty-four hours.

Foucault's gyroscope.—The gyroscope is a device which Foucault employed later for demonstrating the rotation of the earth. The method is not so satisfactory as the pendulum plan, though the principle involved is identical. A heavy disc (Fig. 63) having an axis which turns easily upon pivots, is made to rotate at a high velocity. The rapid revolution of the disc in one plane gives the gyroscope rigidity; consequently a pointer rigidly fixed to the outer ring of metal will remain perfectly still, while the earth will rotate under the gyroscope and carry with it a scale, the instrument, and the table on which they are fixed.

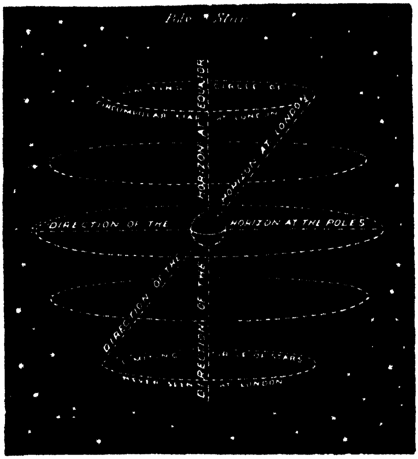
Pole Star
LIMITING CIRCLE OF CIRCUMPOLAR STARS AT LONDON
HORIZON AT EQUATOR
HORIZON AT LONDON
DIRECTION OF THE HORIZON AT THE POLES
DIRECTION OF THE
DIRECTION OF THE
LIMITING CIRCLE OF STARS NEVER SEEN AT LONDON

FIG. 64.—To explain the difference in the apparent diurnal motions of stars when observations are made in different latitudes.

Apparent movements of the stars due to the earth's rotation.—Attention has been directed (p. 90) to the difference in altitude of the pole star which is noticed as an observer travels from the equator towards the poles. The changes may now be considered which are noticed in the apparent movement of the stars as we move either from the equator towards the poles or in a contrary direction. An

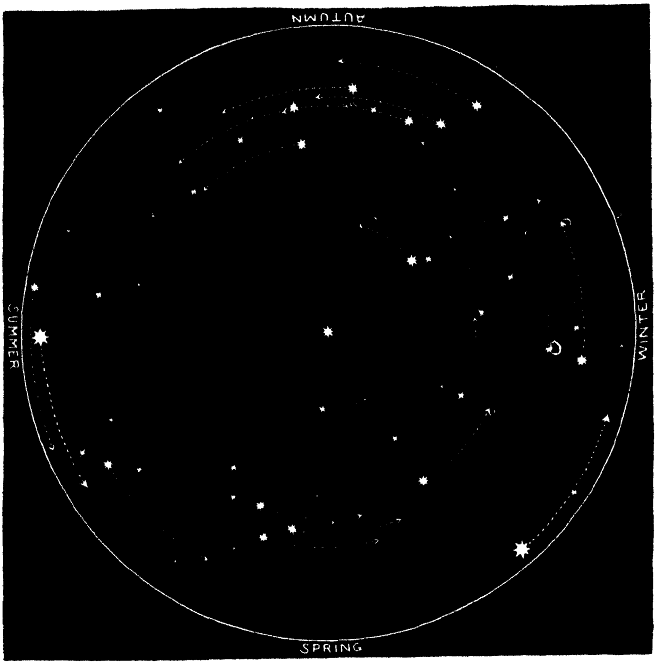

FIG. 65.—Apparent rotation of stars around the north celestial pole. Arrange the diagram so that the name of the season can be read at the bottom, and the stars then occupy the position in which they can be seen about 10 p.m. (Compare with Fig. 5.)

examination of Fig. 64 makes the matter clear. To take in order the three positions of the observer depicted in the illustration :

1. **When the observer is at either of the poles,** say the north, the pole star appears almost exactly overhead : indeed it is so named because if the earth's axis were continued to meet the heavens it would pass almost exactly through this star. The horizon is contained by the plane passing through the earth's equator. All stars appear to move round the observer in circles, and remain visible

throughout their daily journey. Or, it may be said that their apparent paths are always parallel to the horizon.

2. **When the observer is at the equator** the pole star appears on the horizon, and all stars seem to describe semicircles in the heavens. The planes containing the paths of the stars are vertical.

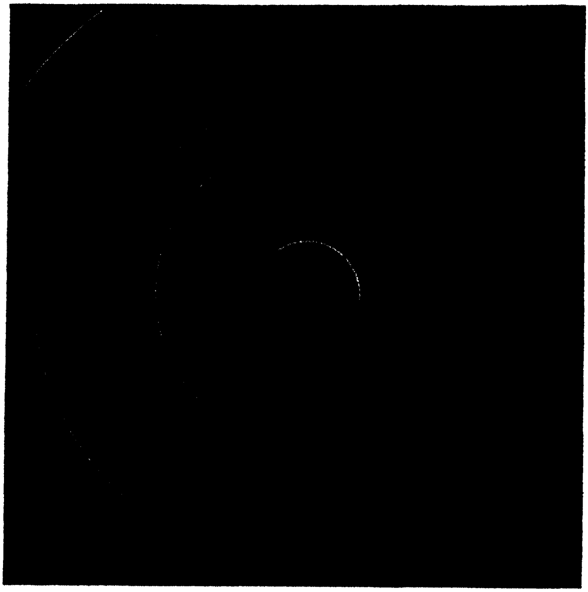

FIG. 66.—Photograph of the apparent rotation of stars round the north celestial pole.

3. **When the observer is in middle latitudes,** say at London, the stars seem to belong to three classes : (i) Those which can be seen throughout the whole of their apparent journey, that is, which never set (these are called *circumpolar stars*) ; (ii) those which are visible for only a part of their apparent path, that is, which both rise and set ; (iii) those which never come into sight at any period of their apparent daily motion, that is, which never rise.

Apparent motion of stars.—If the northern sky be watched on a fine night all the stars will be seen to turn as if they were fixed on a solid vault pivoted at a point near the pole star (Fig. 65). A striking way of showing this is afforded by photography. Whilst the camera is directed towards the sky the stars apparently move round the pole star, the result being that they all leave trails upon the photographic plate (Fig. 66). The pole star traces an arc of a very small circle (thus proving that it is not situated absolutely at the pole), while the other trails are arcs of much larger circles. A similar result is obtained if a photograph is taken of the region around the pole by a photographer in the southern hemisphere. This indicates that the earth *is* in rotation.

11. THE LENGTH OF A DAY

1. Greenwich and local times.—Cut out a ring of cardboard large enough to encircle completely a ball or globe with one or two inches between the inner rim and the surface of the globe. Mark 24 divisions around the ring to represent hours, and number them from i to xii in each half of the ring, letting the numbers read in the opposite direction to those upon the dial of a clock. Place the globe near a lighted lamp, with its axis vertical, and fix the ring on a level with the equator so that one number xii is directed towards the lamp (Fig. 67). Stick a long pin into the globe at the equator on the meridian passing through Greenwich. This pin will serve to show the hour division over the Greenwich meridian at any time. Rotate the globe and notice (*a*) that the Greenwich or any other meridian passes in succession under each of the twenty-four hours marked upon the ring ; (*b*) that the time of day at any place depends upon the position of the place with reference to the sun ;

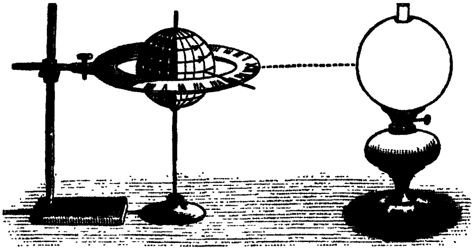

FIG. 67.—Model to illustrate the relation between time and longitude.

(*c*) that if Greenwich time, as shown by the pin, and the time at any place at the same instant are both known, the longitude of the place can be determined.

2. Construction of a sundial.—Obtain a small slab of wood, about a foot square, and varnish the top so that a fine circle can be drawn upon it in ink, or glue paper upon it, and after drawing the circle varnish the paper. Draw a diameter of the circle, and place the slab so that this diameter is due north and south and the sun can shine upon it. Fix a knitting needle at the centre of the wood and inclined to it towards the north at an angle equal to the latitude of the place of observation (Fig. 68). The needle then points towards the North Celestial Pole, and is parallel to the earth's axis. Notice the position of the shadow of the rod at definite hours, say 9 a.m., 11 a.m., noon, 3 p.m., 4 p.m. Draw a line from the centre of the circle in the direction of the shadow at each observed time. You will notice that the shadow does *not* move through the same angle every hour. In our latitude, therefore, the dial of a sundial must not have the hours marked at equal intervals like the hours on the dial of a clock.

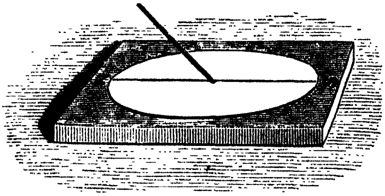

FIG. 68.—Simple horizontal sundial.

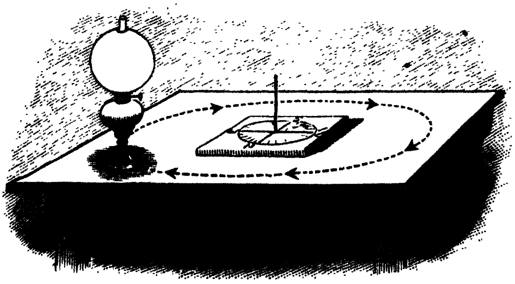

FIG. 69.—To illustrate a sundial at the north pole, and the apparent diurnal movement of the sun there.

3. Apparent daily motion of the sun at the poles.—Draw a circle upon paper or thin cardboard, and divide it into 24 equal parts by drawing lines 15° apart from the centre to the circumference. Number these lines from i to xxiv to represent hours. Fix the circle upon a board or table and stick a knitting needle or thin rod upright at its centre. Place a lamp so that the shadow of the needle can be seen clearly. Carry the lamp round the needle in the way indicated in Fig. 69, and notice the change of direction of the shadow of the needle. At the poles the sun appears to move round the heavens parallel to the horizon in this way during the summer.

4. Construction of sundial for any latitude.—Cut out of cardboard another circle of the same diameter as that in the preceding experiment, and push the knitting needle through its centre. Incline this upper circle so that the knitting needle makes an angle with it equal to the latitude of the place for which the dial is to be divided. Fix the circle in this position by means of a clamp. Place a set-square vertically against each of the twenty-four divisions of the lower circle, and make a mark where it touches the upper one. Now take off the upper circle and draw a line from each mark so obtained to the centre of the circle. These lines represent the hours, the line which was at the lowest part of the card being 12 midnight and the opposite one 12 noon.

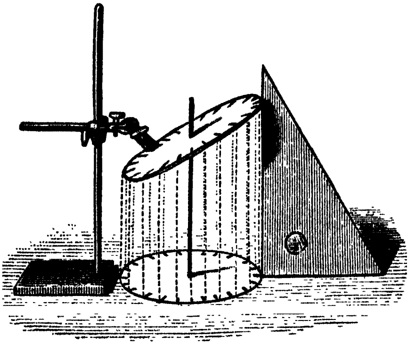

FIG. 70.—How to graduate a sundial for any latitude.

Apparent daily motion of a star.—Most of the stars, like the sun, rise, south, and set. But whereas with the sun the interval between two successive passings across the meridian varies throughout the year, it is found that the time which elapses between two successive similar southings of the same star at any season of the year is always the same. This interval constitutes a star day or **sidereal day**. If, then, some means of ascertaining the exact moment at which a star passes over the meridian of a place can be found, we have a method of measuring time in terms of an interval of time which is always the same.

The **transit instrument,** or any suitably mounted telescope, capable of vertical movement, *i.e.* rotation in a vertical plane, such as a theodolite, affords us such a means. It consists of an astronomical telescope which is fixed firmly between two vertical uprights and supported so that it can move round in a vertical plane (Fig. 71; also Figs. 16, 17 and 38). The eye-piece of the telescope is provided with cross-wires, some vertical and one or two horizontal. When the telescope is moved round, the middle vertical cross-wire traces out a line which passes through a point exactly overhead, called the *zenith*, and also (for the instrument is so fixed) through the north and south points on the horizon. The line thus traced out is, of course, the *meridian*. When, therefore, the image of a star crosses this vertical cross-wire, or **transits**, as we say, we have the exact moment of the star's *southing* (Fig. 72). The interval between such an observation and a similar one with the same star the next night is an exact sidereal day.

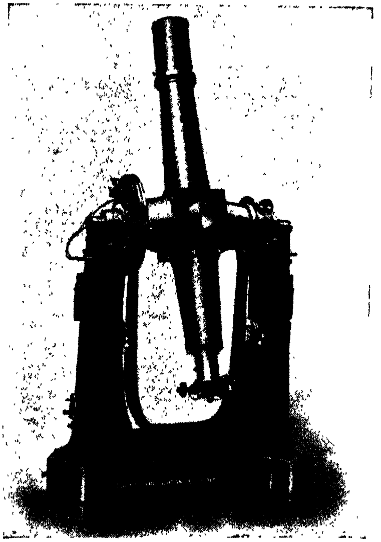

FIG. 71.—Cooke's form of transit instrument.

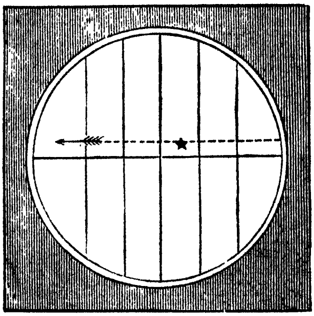

FIG. 72.—Spider lines in the field of view of a transit instrument. The middle vertical line marks the meridian. The direction of motion is that seen with an inverting telescope.

Greenwich and local times.—Let the reader suppose himself above the earth, in the zenith of the north pole, and looking down upon the north pole situated at the intersection of the diameters of the circle which represents the equator of the earth (Fig. 73). The circle is divided into 24 equal parts, and hence the angle between any radius and the next is 360° divided by 24, or 15°. As the globe spins round, each radius in turn occupies the position of that marked " 12 noon ". An observer at a place with this longitude will see the sun in its highest position for the day, or on the meridian. At places of longitude 180° it will be 12 o'clock midnight when at Greenwich it is 12 o'clock noon (see page 109). When the sun is on the meridian at Greenwich, it will be 6 o'clock in the morning and 6 o'clock in the evening respectively at places 90° W. and 90° E.

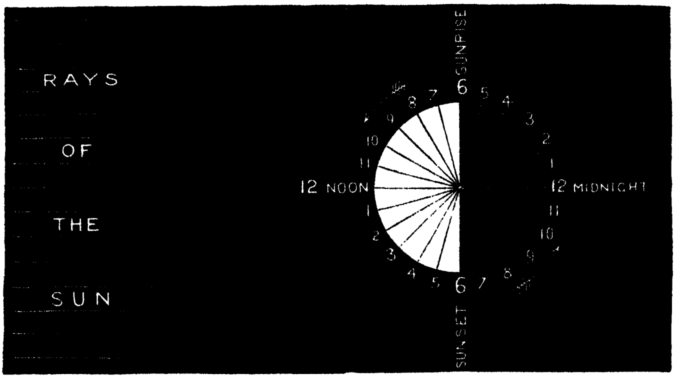

FIG. 73.—Relation between time and longitude. (For the sake of simplicity, the earth is shown illuminated as it would be at the equinoxes (p. 125).)

Again, when it is 12 o'clock noon at Greenwich, at places 15° W. longitude it is 11 a.m., while at places 15° E. longitude the sun has passed the meridian an hour ago, or it is 1 p.m.

Hence **the rule for finding Greenwich time** at a place when the local time and the longitude of that place are known. For places west of Greenwich add to the local time one hour for every 15° of longitude, or four minutes for every degree ; while, for places to the east, subtract the same amount of time. Similarly, if Greenwich time is known and the local time is required, we can, being aware of the longitude, subtract the same amount of time for places west of Greenwich and add it for places of east longitude.

But these facts are most useful in enabling a navigator **to determine the longitude** of his position. If the mariner has with him an accurate chronometer keeping Greenwich time, that is, one which records 12 o'clock when the sun is on the meridian of Greenwich, he can, by noting the time at which the sun crosses the meridian (which happens at 12 o'clock noon local time), tell the difference between local and Greenwich time. If the local time is slow compared with Greenwich time his longitude is west, and equal to a number of degrees obtained by reckoning one degree for every four minutes it is slow. If the local time is fast, he is in east longitude, and on the meridian which is found by dividing in the same way the amount of time he is fast.

The zone or international system of time-reckoning.—In the days when places were not within easy communication with one another, either by rail or telegraph, local time was commonly used. The necessity for a uniform standard became clearly evident when railway time-tables had to be printed. Formerly it was common to see the announcement of railway companies, "London (Greenwich) Time observed at all stations". By the introduction of standard time, order was called out of chaos, though it meant that, for places west of the Greenwich meridian, time indicated by the sun is after the time indicated by clocks. A still further advance was made when the Greenwich meridian was adopted as the prime meridian for the international system of time-reckoning.

Twenty-four standard meridians are now recognised, beginning with Greenwich, and counting towards the east. The time of each of these meridians is thus one hour behind that of the next meridian to the east of it, and one hour in advance of the next meridian to the west. Each meridian may be regarded as the mid-line of a zone 15° of longitude in width, so that the 24 meridians give the standard times on the international system for the whole world. It is usual for places within half an hour of the standard meridian to adopt the time of that meridian as its mean time, but in some cases the line midway between two consecutive meridians of the 24 hour system is taken as the standard meridian.

The subjoined table, from *Whitaker's Almanack*, shows the countries in which this system of standard time, with the prime meridian at Greenwich, has been adopted:

COUNTRY	Central Meridian	Fast or Slow on Greenwich Time
Mid-Europe	15° E.	1 h. fast.
East Europe, British S. Africa, Egypt and Red Sea	30° E.	2 h. fast.
Zanzibar	37° 30′ E.	2½ h. fast.
Perim near Aden *	45°	3 h. fast.
Mauritius and Dependencies	60° E.	4 h. fast.
Afghanistan	67° 30′ E.	4½ h. fast.
Chagos Archipelago	75° E.	5 h. fast.
India †	82° 30′ E.	5½ h. fast.
Calcutta (by I.S.T.)	88° 20′ E.	5½ h. fast.
Burma	97° 30′ E.	6½ h. fast.
Hong Kong, Borneo, West Australia	120° E.	8 h. fast.
Japan	135° E.	9 h. fast.
South Australia	142° 30′ E.	9½ h. fast.
Victoria, New South Wales, Queensland, Tasmania	150° E.	10 h. fast.
New Zealand	172½° E.	11½ h. fast.
Iceland	15° W.	1 h. slow.
America:		
Atlantic	60° W.	4 h. slow.
Eastern	75° W.	5 h. slow.
Central	90° W.	6 h. slow.
Mountain	105° W.	7 h. slow.
Pacific	120° W.	8 h. slow.

* Aden 44° 59′ E. keeps Local Mean Time, *i.e.* 2 h. 59 m. 45 s. fast on Greenwich time.

† The exact local times at the observatories in India are as follows:

Nautical Almanac No.	Name	Altitude	Place	Local Time
				Fast on G.M.T.
38	Govt. Ob., Colaba	19 ft.	Bombay	4 h. 51 m. 15·60 s.
278	M. of Travancore	61 ft.	Trivandrum	5 h. 7 m. 59·00 s.
132	Solar Physics	2343 ft.	Kodaikanal	5 h. 9 m. 52·00 s.
72	Haig Ob., S. of I.	682 ft.	Dehra Dun	5 h. 12 m. 11·79 s.
116	Nizamiah Ob.	554 ft.	Hyderabad	5 h. 13 m. 48·98 s.
159	Madras Ob.	7 ft.	Madras	5 h. 20 m. 59·14 s.
61	Colombo Ob.	6 ft.	Colombo	5 h. 19 m. 28·69 s.
	Alipore	15 ft.	Calcutta	5 h. 53 m. 20·80 s.

Greenwich time is used in France, Spain, Portugal, Belgium, Holland, Gibraltar, and Faröe (Sheep Islands).

The date or calendar line.—Since a new day begins at longitude 180° when it is noon at Greenwich, it is usual on ships to alter the date by one day on crossing longitude 180°, or some convenient meridian about this position. These positions are shown below :

In latitude	Longitude
60° 00′ south	180° 00′
51° 30′ ,,	180° 00′
45° 30′ ,,	172° 30′ west.
15° 30′ ,,	178° 30′ west.
5° 00′ ,,	180° 00′
48° 00′ north	180° 00′
52° 30′ ,,	270° 00′ east.
65° 00′ ,,	169° 00′ east.
70° 00′ ,,	180° 00′

The irregular line at which the change is made is known as the Date or Calendar line. When crossing this line on a **westerly** course the date must be **advanced one day** ; when crossing it on an **easterly** course the date must be **put back one day.**

Sundials.—Though the time of day, as indicated by the sun, can be estimated approximately by noticing the direction of the shadow of an upright object, a properly constructed sundial is necessary if apparent solar time is to be shown accurately. The face of a sundial, upon which the hours are marked, is the **dial** ; and the rod, the shadow of which falls upon the dial when the sun is shining, is the **style** (Fig. 74). The dial of a sundial is usually either horizontal, or vertical and facing south. It may, however, be inclined at any angle and face any direction, provided that **the style lies parallel to the direction of the earth's axis.** The line showing the hour of twelve noon on the dial must also lie in the plane of the meridian of the place in which the sundial is fixed.

As the altitude of the pole depends upon the latitude, the inclination of the style with regard to the horizon must also vary. For a horizontal dial, the style must be inclined to the dial at an angle equal to the latitude of the place. But whether the dial be vertical, horizontal, or inclined at any angle, or whether it faces north, south, west or east, the style should be parallel to the earth's axis.

A sundial which has the style parallel to the earth's axis, and a dial parallel to the plane of the equator, represents the simplest condition of things. Such a dial may be divided into 24 equal parts by lines drawn from the centre to the circumference, and the shadow will pass from one line to the next every hour. This would be the kind of sundial to use at the poles, where a vertical rod is parallel to the earth's axis and a horizontal board is parallel to the plane of the equator.

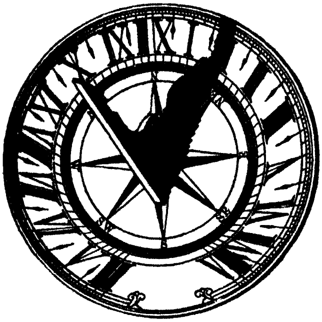

FIG. 74.—Style and dial of a horizontal sundial.

A sundial in any latitude could, of course, be arranged with the dial parallel to the equator, and the style in the direction of the earth's axis, and in this case the hours would be separated by equal intervals. It is, however, more convenient to use a horizontal or vertical dial.

Construction of sundials for any latitude.—At the poles a vertical rod lies in the same direction as the earth's axis, and a horizontal circle is parallel to the equator. As the earth turns on its axis at a uniform rate, the apparent daily motion is also uniform, and the shadow on a horizontal dial changes its position at the uniform rate of 15° per hour.

If 24 meridians of longitude are considered to be drawn upon a terrestrial globe, then, in consequence of the earth's rotation, the sun passes from one meridian to the next (that is, through 15° of longitude) every hour. Imagine the earth to be transparent, like glass, and these meridians to be metal wires upon it. Imagine also, that the earth's axis, instead of being a mere name, consists of a steel rod running from pole to pole, like a knitting needle through an orange. To an observer at the poles of this glass globe, the meridians could be regarded as the lines on the dial of a sundial, while the shadow of a prolongation of the axis could be regarded as the shadow of the style.

Bearing these assumptions in mind, it is easy to understand the principle on which the dial of a sundial is divided for any latitude. The meridians in Fig. 75 represent the hours of the day. A plane parallel to the horizon of the selected latitude is drawn through the earth's centre, at its proper inclination to the equator, the inclination in the diagram being that of the horizon of such places as Omsk and Moscow in the latitude of Edinburgh. Lines are drawn from the points of intersection of this plane with the hour lines (meridians), to the centre of the plane, and are marked with the corresponding numbers. The divisions thus obtained represent the hours on a horizontal sundial for the place chosen. A practical application of the principle is shown in Fig. 70.

Mean solar day.—Equation of time.—A day, as measured by the sundial, that is, the interval between two successive southings of the sun, varies in length throughout the year, and it is not difficult to understand that such a variable day cannot form a convenient standard of time. But if the length of all the days in the year are added together, and the length of a year thus measured by the sun is divided by the number of days in the year, we obtain an interval of time which is always the same. Such a day, which is, of course, an imaginary one, is called a **mean solar day**. Sometimes the mean solar day is longer than the day measured by the sundial, sometimes it is shorter, and occasionally both days are of exactly the same length. Sundial time is known as **apparent time,** and clock time as **mean time.** The amount of time which must be subtracted from or added to the time shown by the sundial, in order to obtain mean solar time, is called the **equation of time.** Its value for every day in the year is given in the *Nautical Almanac* and other publications. All clocks and watches keep mean solar time, and consequently there is usually a difference between the time recorded by the sundial and that given by a correct clock.

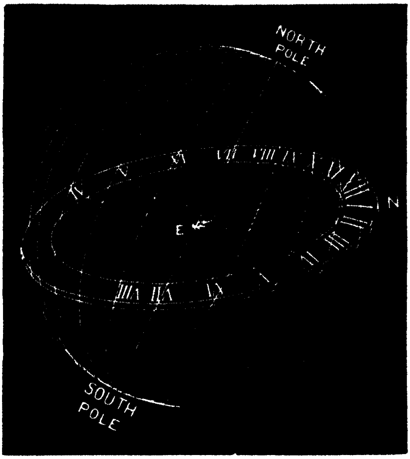

FIG. 75.—To illustrate the principle upon which sundials are graduated.

The Calendar.—The following extract from the *Nautical Almanac* will be of considerable interest to students who desire information on the major divisions of time.

" A Calendar is a method of combining days into periods adapted to the purposes of civil life etc., such as weeks, months and years. Three of the periods used in Calendars, namely days, months and years, are based on those astronomical periods which have the greatest importance for the conditions of human life. Other measures of time, such as the weeks and sub-divisions of the day, are artificial . . . ."

"Our whole system of measuring time depends on the movements of the earth, the sun and the moon. The earth rotates on its axis once per day and revolves round the sun once per year. The axis of the earth points towards the pole star, and its inclination to the plane of the earth's orbit is the cause of the seasons. Since it takes approximately 365 days for the earth to travel 360°, then in one day the angle moved through is 1°. Since also the earth rotates 360° in 24 hours it will cover 1° in 4 minutes travel. Thus the time for two successive "southings" of the sun is longer by 4 minutes than the crossings of the meridian by a star.

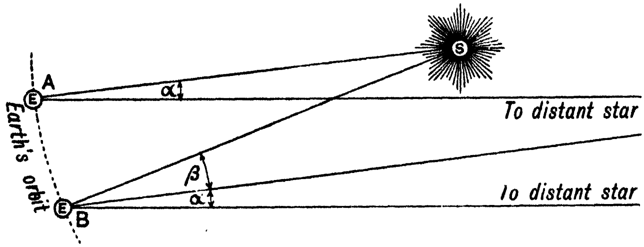

FIG. 76.—When the earth has moved along its orbit from *A* to *B* the *southing* of sun is later by the angle β compared with the *southing* of the star observed from *A* and again from *B*. Thus when the earth has travelled 90° along its orbit the *southing* of the sun will be 90° later than the *southing* of the star or 6 hours later roughly.

"The shorter period is the **Sidereal day** as against the longer period of the **Solar day**. The stars are more accurate time keepers than the sun. A sidereal day depends only on the rotation of the earth, while a solar day depends on the revolution of the earth round the sun. When the earth is nearer the sun its rate of travel is greater than when it is further away. The difference between the sidereal day and the solar day varies throughout the year. A sun clock or sundial indicates the length of the day in solar time, but it is impossible to make a clock to keep strict solar time. A watch keeps average time, *i.e.* the average length of a solar day—sometimes it will be slow and sometimes fast by the sun. The difference between sundial and watch time is called the **equation of time**. It may vary from + 15 to – 15 minutes, and is 0 on April 15, June 15, August 31 and December 24.

"The moon rotates round the earth, *i.e.* 360°, in 27 days 8 hours, but from new moon to new moon, owing to the earth moving on its orbit, the moon takes 29½ days (a lunar month). Twelve lunar months equal 354 days or eleven and a quarter days short in the year. In early days the moon marked the important divisions of time. Thus midsummer arrived 11¼ days too soon each year and would be in midwinter in a few years. To avoid this, days were added from time to time.

"The Egyptian year from an extremely remote date consisted of 12 months of 30 days, followed by 5 days "added". This 30 day period was obviously based on lunation so that the calendar must at some date have been governed by the moon, while its primitive connection with the solar year is proved by the three seasons—Flood time, Seed time and Harvest time. However, before the earliest times known to us all attempts to equate the calendar month to the phases of the moon and to the natural seasons had been abandoned.

"Julius Caesar in B.C. 47 on the advice of Sosignes of Alexandria, fixed the year at 365¼ days, adding the day every fourth (leap) year.

"The Julian Calendar made the year 11¼ **minutes** too long, and by 1582 was nearly 10 days too slow when Pope Gregory XIII put the calendar forward by calling October 5, October 14 and it was agreed to omit three leap years every four centuries. England adopted the Gregorian calendar in 1752, when the error had become 11 days. Wednesday, September 2 was followed by Thursday, September 14, but this led to rioting, demanding the Government to give back the eleven days. Russia and Greece did not give up the Julian Calendar until the Great War (1914-18) when the difference, slow, was 12 days.

"The complexity of calendars is due mainly to the incommensurability of the astronomical periods on which they are based. The supply of light by the two great luminaries is governed by the periods known to astronomers as the **solar day** and the **synodic month,** while the return of the seasons depends on the **tropical year.** The length of the synodic month at the present time is 29·5305879 days, while that of the tropical year is 365·24219 days, each period being subject to an uncertainty of about one unit in the last figure given. Both periods are slowly decreasing, the synodic month or lunation by about 3½ units in the last figure every century, and the year by about one unit in the last figure every century. From the length of these two periods we find that the number of lunations in a tropical year is 12·3682668, decreasing by about 2 units in the last figure every century."

EXERCISES ON CHAPTER IV

1. Find the latitude and longitude of a place which is 6000 miles east of Greenwich and 1400 miles north of the equator.

2. What is longitude, and how does it affect time? What would be the local time and day in Karachi (time of 67° E.) and Shillong (time of 92° E.) corresponding to Greenwich mean time 6 p.m. Monday?

3. Explain what is meant by saying

(*a*) Karachi and Samarqand have the same longitude.

(*b*) Quetta and Lhassa have roughly the same latitude.

(*c*) The time at Calcutta is 24 minutes slow by Indian Standard time.

4. At three places in England the sun rises at the clock times undermentioned :

	A.	Greenwich	C.
On 20th March - -	6.29	6.7	6.15
On 21st June - -	4.18	3.45	3.29

State how A and C lie with respect to Greenwich in latitude and longitude, and give the direction, if you cannot give the amount of difference.

5. Indian Standard time is about 60 minutes slow by standard time in Burma and 60 minutes fast by the time adopted for Afghanistan. Explain fully the meaning of this statement.

6. On a complete journey round the world from east to west a day is apparently " lost ", but if the journey is made from west to east a day is apparently " gained ". Account for this, explaining the meaning and use of the " date-line ".

7. Explain why the length of a degree of latitude is nearly the same in all latitudes, while that of a degree of longitude diminishes as latitude increases.

8. Find the approximate distance in miles between two places, one in 40° N. latitude and 3° E. longitude, and the other in 50° S. latitude and 150° W. longitude.

9. Show, with the help of a diagram, how to find the pole star. How can the latitude of a place be found from observations of the pole star?

10. Compare the length of a degree of latitude with the length of a degree of longitude : (*a*) at the equator, (*b*) near the poles, (*c*) half-way between the equator and the poles.

11. Calculate and explain the difference in longitude between two places whose local time differs by one hour. If the longitude of Chittagong is 92° E., find the local time there when it is noon at Greenwich. Why is there no local time at the poles?

12. State concisely the proofs of the earth's spherical shape.

13. The Hindu Kush mountains are 68 degrees east of Greenwich, and the Arakan Yomas are 94° east of Greenwich. What time is it on the Yomas when it is 1 p.m. on the Hindu Kush mountains? Show how you arrive at your answer.

14. State what you know of the form and size of the earth. How can the former be demonstrated?

15. When it is 12 noon at Greenwich, what is the time at San Francisco (long. 122½° W.)? Also find what time it will be at Greenwich when it is 4.30 p.m. at Calcutta (long. 88½° E.).

16. Explain what is meant by longitude.

If you were on a cycling tour on the coast of Madras you would find that your lighting-up time would be about 25 minutes later than that for Calcutta. How do you account for this?

If the lighting-up time for Calcutta on a certain day is 8 p.m., what do you think that at Bombay would be?

17. Explain fully why time varies according to longitude. Given that the longitude of Canton is 114° E., Bagdad 44½° E., and Bombay 73° E., find the time at each of these towns when it is midday at Greenwich.

18. When it is 2 a.m. on Thursday at Greenwich it is 9 p.m. on Wednesday at Ottawa and noon on Thursday at Sydney. Calculate the longitude of these places.

19. What do you understand (*a*) by the sun crossing the meridian, (*b*) by Greenwich time?

A man travelling from Peshawar to Kabul notices on his arrival that there is a difference of one hour between his watch (Indian Standard time) and Afghanistan time. How is this?

The longitude of Bombay is 72° 50′ E., of Charleston 80° 40′ W. What time is it at each of these places when it is noon at Greenwich?

20. What time is it in Chicago and in Calcutta when it is midday in London (Greenwich)? Give the explanation of this in language simple enough, and with a setting vivid enough, for a child of ten to understand. (A series of lessons is not asked.)

21. Explain fully what is meant by the latitude and longitude of a place. A cricket match at Melbourne (longitude 145° E.) was finished at 5 p.m. on Saturday. Assuming that the time occupied in sending a cable message from Melbourne to Calcutta is two minutes, determine at what time the result could be announced in Calcutta. Give your reasons.

22. How do you account for the variation of time all over the world? When it is noon at Greenwich, what time is it at New Orleans (90° west longitude) and at Aden (45° east longitude)?

MY TIME IS IN THY HAND
VI
VII
VIII
IX
X
XI
XII
I
II
III
IV
V
LET OTHERS TELL OF STORMS & SHOWERS
I'LL ONLY COUNT YOUR SUNNY HOURS

Fig. 77.—Sundial on south wall at Sandringham.

CHAPTER V

THE EARTH AS A PLANET (*Continued*)

12. THE REVOLUTION OF THE EARTH

1. Measurement of sun's noonday altitude. (*Outdoor work.*)—Fix a thin rod upright in a drawing-board, or suitable piece of wood. Draw a line upon the wood passing through the point in which the rod is fixed. Place the board out of doors, so that it is horizontal and the line upon it lies due north and south. (If the true north and south direction is not known, it should be found as described in Chap. I.) When the shadow of the rod falls upon the line, that is, at noon, mark upon the board the point where the end of the shadow touches the line. Stand a piece of cardboard upright upon the north and south line, and mark upon it three points (i) at the bottom of the rod, *C* (Fig. 78); (ii) at the top of the rod, *A*; (iii) at the point reached by the end of the shadow, *B*. Connect these points and measure the angles *ABC* and *BAC* with a protractor. The angle *ABC* shows the altitude of the sun at noon on

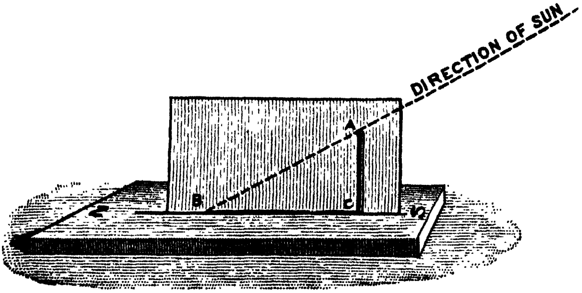

FIG. 78.—Method of measuring roughly the altitude of the sun at noon.

the day of the observation, while the angle *BAC* shows its angular distance from the zenith. On March 21 and September 23, notice that the latter angle is the same as the latitude of your position. On June 21 it is equal to 23½° less than your latitude, and the sun's altitude is therefore 23½° greater than on March 21 or September 23. On December 21 the angle *BAC* is 23½° greater than your latitude, and the sun's altitude is therefore 23½° less than on March 21 and September 23.

Explain how, on any of these dates, an explorer could determine the latitude of his position, provided that he could see the sun at midday.

2. Conditions for a constant noonday altitude.—Place a lighted lamp upon a table, and near it a small globe, or a tennis ball with a knitting needle through its centre, forming an axis. Arrange the globe, or ball, with the axis perpendicular to the table, as in Fig. 79, and the equator on a level with the light of the lamp. Carry the globe around the lamp on this level and notice:

(*a*) that the light, which represents the sun, is directly overhead at the equator in every position of the globe;

(*b*) that the direction, with reference to the zenith or to the horizon, of a line from the light to any place at noon (that is, when the place directly faces the light) depends upon the latitude, and is constant for any one latitude;

(*c*) that during a complete spin of the globe every place faces the light for half the period of spin, and is in the dark for the other half.

The model thus illustrates that, **if the earth revolved round the sun with its axis perpendicular to the plane of its orbit** (called the plane of the elliptic), the sun would always have the same altitude at noon at any one place, and this altitude would depend upon the latitude of the place. Also, that day and night would be of equal length everywhere throughout the year.

3. Explanation of inclination of equator to ecliptic.—Incline the axis of the globe, or ball, about 23½° out of the vertical, or 66½° from the level of the table. Place the globe in the four positions represented in Fig. 79, the axis being kept pointing in a constant direction. Notice that:

(*a*) at our midsummer (summer solstice) the light is directly overhead in latitude 23½° north of the equator (Tropic of Cancer);

(*b*) at our midwinter (winter solstice) the light is directly overhead in latitude 23½° south of the equator (Tropic of Capricorn);

(*c*) at two positions in spring and autumn respectively, known as the equinoxes, the light is directly over the equator.

Carry the globe completely round the lamp to represent the earth's annual revolution round the sun.

Notice that, on account of the inclination of the axis, the sun's apparent position, seen from the equator, varies gradually from lat. 23½° north to lat. 23½° south. At places on the earth, between lat. 23½° north and lat. 23½° south of the equator, the sun is directly overhead at noon twice in the course of a revolution.

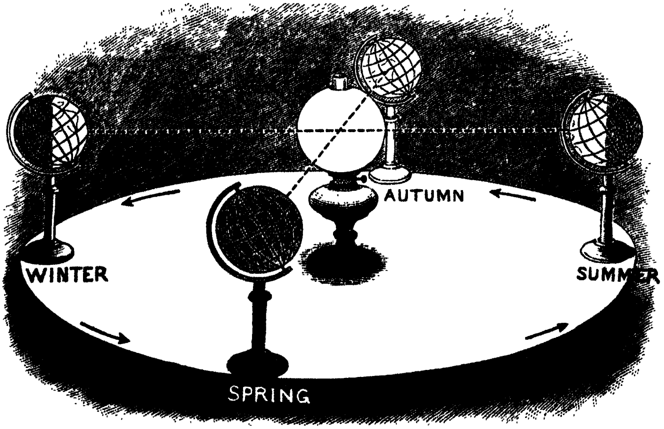

FIG. 79.—To explain how the annual changes of the sun's noonday altitude are produced by the inclination of the earth's equator to the plane of the eclipse.

4. Explanation of variation of sun's noonday altitude.—In the position of Delhi, stick a long pin into the globe, pointing to its centre. The other end of the pin will point to the zenith of Delhi. Place the globe successively in the four positions of the equinoxes and solstices as before, and in each case arrange the globe to make the pin face the light, so as to represent the position of Delhi at noon. Notice that:

(*a*) at the summer solstice the direction in which the light is seen at noon is not far from the zenith (this represents the high sun of summer);

(*b*) at the winter solstice, the light is seen much nearer the horizon, or further from the zenith, of Delhi than in summer;

(*c*) at the equinoxes, the light at noon is seen in a direction midway between the extreme points of summer and winter.

The annual variations of the sun's noonday altitude at any place can be explained similarly by the inclination of the earth's equator, or axis, to the plane of the ecliptic, that is, to the plane of revolution around the sun.

5. Experiment illustrating variation in the length of day and night.—(*a*) Place the globe in the position for the *spring equinox*, and spin it in this position to represent the diurnal rotation of the earth. Notice that every part of the earth is turned towards the light during half of a complete rotation (half a solar day) and away from it during the other half.

(*b*) Place the globe in the position for our *midsummer day* (sun 23½° north of equator) and spin it. Notice that:

(i) every place in the northern hemisphere is longer in illumination than in darkness;

(ii) the north polar regions are not turned away from the light at all during the rotation of the globe;

(iii) The south polar regions are in darkness throughout the rotation.

(*c*) Place the globe in the position for our *midwinter day* (sun 23½° south of the equator) and notice that:

(i) places in the northern hemisphere are in darkness longer than in illumination during a spin of the globe;

(ii) the south polar regions are in illumination during the complete rotation;

(iii) the north polar regions are in darkness throughout a rotation.

6. Sunlight and the earth.—(*a*) With soft wax fix a drawing-pin with the stalk pointing upward at the position of England on a terrestrial globe. Arrange the globe so that the drawing-pin is directed to the zenith, that is, is vertical, and the globe is in a position where the sun can shine upon it. When a globe is so arranged, half of it will be seen to be illuminated by the sun and half to be in darkness. At whatever time of day or year the observation is made, the actual part of the earth lit up by the sun is exactly that seen to be illuminated on the globe.

(*b*) Keeping the globe in the same position as in (*a*), fix a drawing-pin in a narrow strip of cardboard, and move the strip about on the globe, stalk upwards, until the stalk of the pin has no shadow. The part of the globe under the pin is the place on the earth where the sun is in the zenith at that instant. The position of the pin shows also the distance of the sun north or south of the equator on the day of observation.

7. Estimation of length of day at different latitudes and seasons.—(*a*) Notice that in any position of the globe:

(i) the fraction of any circle of latitude which is illuminated is equal to the fraction of a day during which places on that latitude enjoy daylight;

(ii) that the centre of the illuminated hemispherical surface is a point which has the sun in its zenith.

(*b*) Open out a pair of compasses until when one point is on the equator of your globe the other point just reaches the pole. Notice:

(i) that a circle of this radius, described from a point on the equator as centre, cuts each circle of latitude into two equal parts, indicating that when the sun is overhead at the equator, day and night are equal all over the earth;

(ii) that a circle of this radius, described from a centre on the Tropic of Cancer, (α) includes all places between the north pole and lat. 66½° N., (β) excludes all places between the south pole and lat. 66½° S.; and (γ) cuts all other lines of latitude except the equator into unequal parts representing in each case the proportion of daylight and darkness at that latitude on our midsummer day;

(iii) that a circle of this radius described from a centre on the Tropic of Capricorn (α) includes all places between the south pole and lat. 66½° S., (β) excludes all places between the north pole and lat. 66½° N., and (γ) cuts all other lines of latitude except the equator into unequal parts representing in each case the proportion of daylight and darkness at that latitude on our midwinter day;

(iv) that these and all other great circles bisect the equator, indicating that at the equator day and night are equal throughout the year.

(*c*) Using a globe and compasses, determine in this manner the number of hours of daylight enjoyed per day by places on latitude 60° N. at dates when the sun is overhead at latitudes 5° N., 10° S., 15° N., 23½° N., 23½° S. respectively.

(*d*) Referring to the table given on p. 124, estimate the number of hours of daylight at (i) London, (ii) Melbourne, (iii) Calcutta, (iv) Alexandria, on the first day of each month of the year.

Revolution of the earth round the sun.—The earth, in addition to its regular rotation upon its axis, has another motion which carries it round the sun on a fixed path, called its **orbit**, once a year. The earth's orbit is an ellipse, differing little in form from a circle. Imagine a plane passing through the centre of the earth and the centre of the sun, such that the earth's centre will fall in this plane at all times of the year, that is, whatever the position of the earth on its orbit may be. This plane, containing the earth's orbit, is called the **plane of the ecliptic.**

Or, to put the same fact in another way, the earth and sun may be imagined as floating in a boundless ocean, both of them being half immersed, or sunk as far as their centres. In these circumstances the surface of such an ocean would be the plane of the ecliptic. The earth must be supposed to float in such a manner that its axis makes an angle of 66½° with the surface of the ocean, because the axis of the earth is inclined at an angle of 66½° to the plane of the ecliptic. The plane containing the earth's equator is known as the plane of the equator, and from the inclination of the earth's axis it follows that **the plane of the equator and the plane of the ecliptic are inclined to one another at an angle of 23½°.**

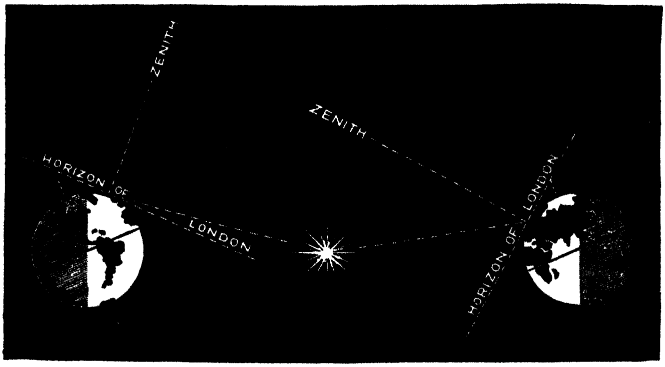

FIG. 80.—To explain the differences of altitude of the sun in summer and winter, as observed from London.

Some consequences of the inclination of the earth's axis.—The earth's axis, whatever its position on its orbit, is inclined at the same angle always. Or, at the various positions of the earth in its annual journey round the sun the directions of the axis always remain parallel to one another. The axis always seems to point in the same direction in space, and near that point in the sky at which the pole star is seen.

It is due to this inclination of the earth's axis that the midday sun has a different altitude at different times of the year. Fig. 80 shows the positions of the earth at midwinter and midsummer respectively in the northern hemisphere. At our midwinter, when the earth is in the left-hand position of Fig. 80, the north pole of the earth's axis points away from the sun. It is clear that to an observer in London the sun will appear very near the horizon. When six months later, the earth has reached the right-hand position of Fig. 80, the north pole of the axis points towards the sun, and the observer in London will now see the sun much nearer the zenith than when the earth was in its midwinter position.

Annual variation of the sun's midday altitude.—The daily variations in the length of the shadow of a fixed object, as the sun describes its daily apparent path in the sky, has been described already. The noonday shadow is the shortest shadow for the day, but the observations of this shortest shadow, day by day, will show that its length varies throughout the year. In summer, the noonday shadow is comparatively short, and from midsummer to midwinter it gradually lengthens, while from midwinter to midsummer it gets shorter and shorter, day by day.

It has been seen in Expt. 1, sect. **12**, that the length of a noonday shadow affords a means of finding the **altitude**, or angular distance above the horizon, of the sun at noon; the angle of altitude subtracted from 90° naturally gives the sun's angular distance from the zenith. *The angle between the celestial equator and the zenith of any place is equal to the latitude of that place.* Twice a year—on March 21 and September 23—the sun is on the celestial equator, and it follows that on these two dates the noonday sun is in the zenith of an observer on the equator. On these dates also the angle between the noonday sun and the zenith is equal to the latitude of the place of observation. On June 21, an observer in the northern hemisphere sees the noonday sun at an angular distance from the zenith which is equal to his latitude *minus* 23½°; on this date, therefore, the noonday sun is in the zenith of places of latitude 23½° N., *i.e.* of places on the Tropic of Cancer. On December 21, an observer in the northern hemisphere sees the noonday sun at an angular distance from the zenith which is equal to his latitude *plus* 23½°; and on this date the noonday sun is in the zenith of places of latitude 23½° S., *i.e.* of places on the Tropic of Capricorn.

The following table shows at what latitudes the noonday sun is in the zenith from month to month :

Date	Latitude along which noonday sun is in the zenith	Date	Latitude along which noonday sun is in the zenith
January 1 -	23° S.	July 1 - -	23° N.
February 1 -	17° S.	August 1 -	18° N.
March 1 - -	7° S.	September 1 -	8° N.
March 21 - -	**0°**	**September 23** -	**0°**
April 1 - -	5° N.	October 1 -	3° S.
May 1 - -	15° N.	November 1 -	14° S.
June 1 - -	22° N.	December 1 -	22° S.
June 21 - -	**23½°** N.	**December 21** -	**23½°** S.

Variation in length of days and nights throughout the year.—Fig. 81 shows the earth in four positions on its orbit, and the student will recognise the left and right-hand positions as those of midwinter and midsummer respectively. Let us begin with the first of these, and refer only to the northern hemisphere, remembering that it is necessary to reverse this order to know the changes which occur south of the equator. In whatever position the earth may be, one-half of it will be illuminated always, and were the axis of the earth perpendicular to the plane of the ecliptic the day and night would be just twelve hours long always. Supposing the earth in its mid-winter position, we must think of it as continually spinning round upon its axis, and imagine ourselves on some middle parallel of latitude, say, at London.* The latitude, *i.e.* the distance north of the equator, remains the same, and hence during a complete rotation a circle is described round the earth parallel to the equator. Now, if such a latitude circle be imagined round the earth when it is in this left-hand position, it is clear that a larger part of the latitude circle will be in the dark than will be in the light. This is the same as saying that the observer is in the dark for a longer time than he is in the light, or for him the nights are longer than the days. Further, the length of daylight and darkness will be respectively proportional to the fractions of the circle which are lit up and the reverse. In this position the north pole, and all places within 23½° from it, never come into the light, so that places within the circle called the **Arctic circle** have a continuous night. It also follows that between the Arctic and Antarctic circles sunrise is latest and sunset earliest in the most northerly latitudes.

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* The Mihman Yali pass, 18,089 feet, about the most northerly place in India, is in latitude 37° 30′, whereas the latitude of London is nearly 51° 30′.

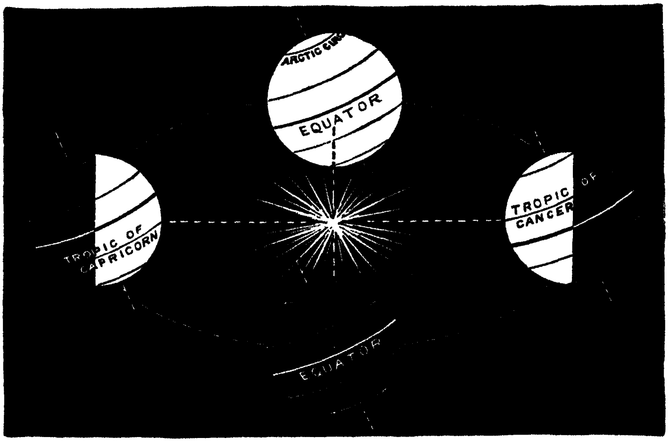

FIG. 81.—The earth in its orbit at the equinoxes and solstices.

When, six months later, the observer at London has been carried with the earth to the right-hand position in Fig. 81, the greater part of a latitude circle, representing his path as the earth rotates, will be in the light, or for him the days will be longer than the nights. At this time places within the Arctic circle never get out of reach of the sun's rays, or for its inhabitants there is continuous day; while between the Arctic and Antarctic circles, sunrise is earliest and sunset latest in places having the most northerly latitudes. This is the explanation of the familiar fact that the days are longer in summer—May to July—and shorter in winter—November to January—in Kashmir than in Mysore or Travancore.

The equinoxes.—At the two places on the top and bottom of Fig. 71, midway between the extreme positions described, just one-half of the circle marked out by the observer during a single spin of the earth is in the light, and just one-half in the dark. That is, in these two positions the days and nights are exactly equal in length. These positions are called **equinoxes.** One, when the earth is on its way towards midsummer, is called the **spring** or **vernal equinox,** and occurs on March 21. The other, when the earth approaches winter, is the **autumnal equinox,** which falls on September 23.

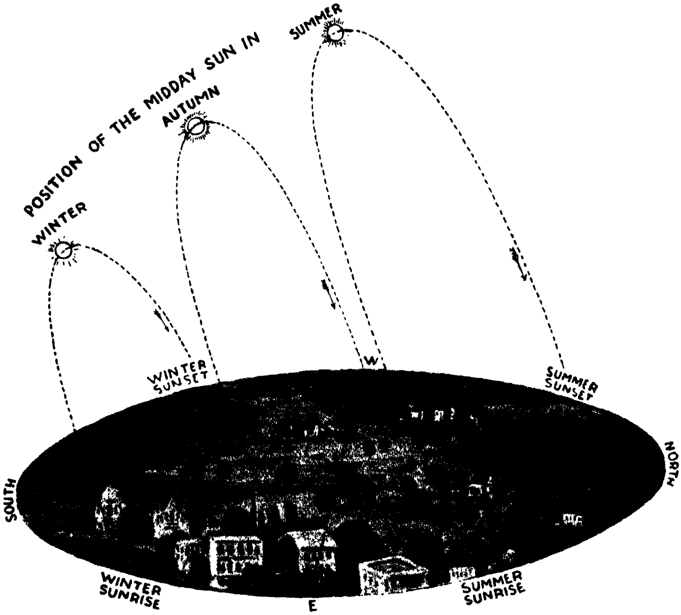

FIG. 82.—Position of sunrise and sunset to an observer about the latitude of Lahore where in summer the sun rises north of east and sets north of west, while in winter the sun rises south of east and sets south of west.

Sunrise and sunset.—Fig. 82 illustrates the varying direction of the sun's rising and setting at different times of the year. If we imagine ourselves at the intersection of a meridian and a parallel of latitude, and bear in mind that the meridian runs north and south and the parallel east and west, we shall understand readily why, at the moment when the rotation of the earth is carrying our position from light into darkness in summer, the sun must appear to the north of west. Similarly, on the other side of the globe representing summer, from a position emerging from darkness into light the sun will appear to the north of east. On the other hand, in winter the conditions will be exactly reversed, the rising sun being seen to the south of east and the setting sun to the south of west (Fig. 82). Half way between these extreme positions, that is, at the equinoxes, the sun will naturally rise exactly in the east and set exactly in the west.

The times of sunrise and sunset for 1936 are shown in the accompanying table of the sun's declination.

Times of Sunrise, Sunset, Moonrise, Moonset, True Noon and Sun's Declination for 1936, in Indian Summer Time

Date	Sunrise h. m.	Sunset h. m.	True Noon h. m.	Moonrise h. m.	Moonset h. m.	Declination
Jan. 1	7 12	6 12	0 42	0 2 p.m.	—	23° 6′ **South**
,, 11	7 14	6 18	0 46	8 43 p.m.	8 54 a.m.	21° 59′ ,,
,, 22	7 15	6 23	0 50	5 19 a.m.	4 33 p.m.	19° 56′ ,,
,, 30	7 14	6 31	0 52	11 26 a.m.	—	17′ 58′ ,,
Feb. 6	7 12	6 34	0 53	5 43 p.m.	6 11 a.m.	15° 58′ ,,
,, 24	7 2	6 42	0 52	7 52 a.m.	8 26 p.m.	9° 53′ ,,
March 5	6 56	6 42	0 51	4 30 p.m.	4 51 p.m.	6° 7′ ,,
,, 21	6 42	6 50	0 47	4 57 a.m.	5 3 p.m.	0° 10′ **North**
April 3	6 32	6 53	0 42	4 7 p.m.	4 5 a.m.	5° 15′ ,,
,, 28	6 12	7 00	0 36	0 21 p.m.	0 47 a.m.	14° 6′ ,,
May 8	6 7	7 3	0 35	8 44 p.m.	7 5 a.m.	17° 2′ ,,
,, 26	6 2	7 10	0 36	11 5 a.m.	—	21° 6′ ,,
June 10	6 1	7 15	0 38	11 26 p.m.	10 32 a.m.	23° ,,
,, 21	6 3	7 19	0 40	8 30 a.m.	9 46 p.m.	23° 27′ ,,
July 8	6 7	7 20	0 43	10 7 p.m.	9 24 a.m.	22° 30′ ,,
,, 23	6 14	7 18	0 45	10 7 a.m.	10 17 p.m.	20° 7′ ,,
Aug. 5	6 16	7 13	0 45	8 46 p.m.	8 12 a.m.	17° 2′ ,,
,, 18	6 20	7 5	0 43	7 10 a.m.	7 42 p.m.	13° 10′ ,,
,, 27	6 22	6 59	0 40	2 44 p.m.	1 4 a.m.	10° 8′ ,,
Sept. 10	6 25	6 47	0 36	1 27 a.m.	2 59 p.m.	5° 1′ ,,
,, 23	6 27	6 36	0 31	0 36 p.m.	11 49 p.m.	0° 1′ **South**
Oct. 6	6 30	6 25	0 28	11 21 p.m.	0 1 p.m.	5° 3′ ,,
,, 19	6 34	6 12	0 25	9 39 a.m.	8 53 p.m.	9° 55′ ,,
,, 31	6 38	6 6	0 23	7 5 p.m.	7 35 a.m.	14° 3′ ,,
Nov. 13	6 44	6 2	0 23	5 23 a.m.	5 21 p.m.	17° 55′ ,,
,, 27	6 53	6 0	0 25	4 45 p.m.	5 11 a.m.	21° 6′ ,,
Dec. 3	6 56	6 9	0 28	10 49 p.m.	11 0 a.m.	22° 5′ ,,
,, 12	7 2	6 3	0 32	5 29 a.m.	4 47 p.m.	23° 4′ ,,
,, 22	7 7	6 7	0 38	0 36 p.m.	0 30 a.m.	23° 27′ ,,

The seasons.—The alternation of the seasons is also the outcome of the inclination of the earth's axis. During the day our planet is receiving heat from the sun continually, which it radiates into space during the night. Now, *where the days are longer than the nights,* it is evident that, in the absence of other disturbing circumstances (see Chapter XII), more heat is received during the hours of light than is radiated throughout the night, or *there is a net gain of heat.* Whereas, if the opposite holds true, and the nights are longer, there is a *net loss of heat.*

Reference to Fig. 81 shows that, as the earth moves round its orbit in the opposite direction to the hands of a watch, from its mid-winter position through the spring equinox towards midsummer, there is *in the northern hemisphere* a gradual increase in the lengths of the days and in the sun's altitude, and consequently a net gain of heat ; while after the midsummer position has been passed and the earth is moving on through the autumnal equinox towards mid-winter again there is a net loss of heat and *the northern hemisphere becomes gradually colder.*

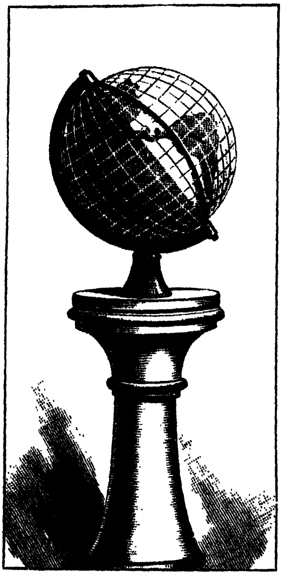

FIG. 83.—A sundial globe.

Illumination of a fixed globe.—Though the earth rotates on its axis and revolves around the sun, thus causing day and night and the seasonal changes which have been described, yet precisely the same effects would be produced if the earth were fixed and the sun revolved around it in the plane of the ecliptic once a day. When a terrestrial globe is fixed so that its axis is parallel to the earth's axis and the meridian of the place of observation faces due south, as in Fig. 83,* then, however the sun shines upon it, the hemisphere of the real earth illuminated at the same time is exactly the same as on the globe. Such a globe enables the declination of the sun to be determined on any day when the sun is shining; for the point on the globe where an upright pin has no shadow gives directly the position of the sun with reference to the equator. By dividing the equator into twenty-four parts to represent hours, or meridian lines, the globe can be used as a sundial. A movable half-meridian is turned until it is under the sun; its shadow on the equator then shows the apparent time.

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* This form of sundial globe, made in pottery so that it can be set up in the open air, was devised by Sir Richard Gregory.

13. THE MOON AND ECLIPSES

1. Phases of the moon.—Find the time of New Moon from a calendar. Observe the crescent moon, about the time of sunset, two or three nights later. Notice that the horns of the crescent moon are always directed *away* from the Sun. When you think it is Half Moon, reckon the number of days that have elapsed since New Moon. In a similar way, find the number of days from Half Moon to Full Moon, from Full Moon to Last Quarter, and from Last Quarter to New Moon. The shape of the moon should be drawn from week to week in connection with these observations.

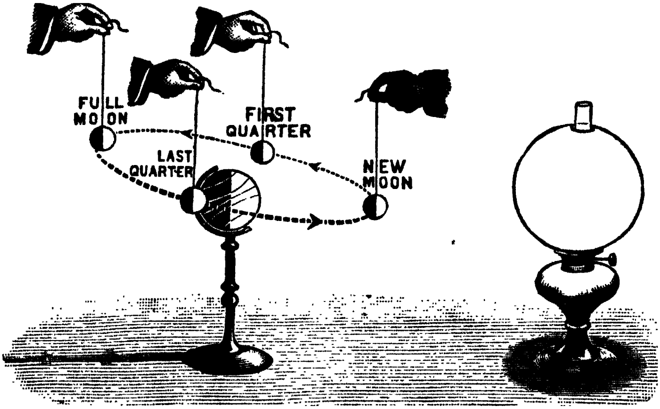

FIG. 84.—Experiment to illustrate the cause of phases of the moon.

2. Explanation of phases of the moon and related phenomena.—(*a*) Place a lighted lamp upon a table, and a globe at a short distance from it; these represent respectively the sun and earth. Obtain a small white ball—about one quarter the diameter of the globe—to represent the moon. Carry the ball around the globe as indicated in Fig. 84, and notice that though a hemisphere of the ball is illuminated always, the amount of illuminated surface visible from the globe depends upon the relative positions of the lamp, globe and ball. Show in this way the relative positions of the three bodies, at the times of (i) New Moon, (ii) Half Moon, (iii) Full Moon, (iv) Half Moon again.

(*b*) Notice that when the ball is between the globe and lamp only the dark side is turned towards the globe. This represents the condition for the astronomical New Moon. Move the ball a little in the direction indicated, and a crescent of light can be seen from the globe, just as the crescent moon becomes visible a few days after New Moon.

3. Movements of the moon with reference to the fixed stars.—(*a*) Notice the position of the moon on any night. Repeat the observation several nights in succession at the same hour. Observe that every night the moon is further east at the same hour than it was the night before. Notice that, on account of this, the position of the moon with reference to the sun and stars constantly changes.

(*b*) Fix a simple theodolite or pointer so that a sight can be taken due south. Observe, on several nights in succession, the times at which the moon appears due south. The time of transit (p. 105) will be found to be about 50 minutes later every night. The times of rising and setting may be expected to be correspondingly belated. Test this surmise by means of the times of rising or setting of the moon given in an almanac. In which phases (Fig.86) does the moon respectively rise and set in daylight?

4. Explanation of eastward motion of the moon.—Place the lamp, ball, and globe upon the table as in Expt. 2, Sect. 13. Imagine objects and marks upon the walls, floor, and ceiling of the room, to represent stars. Carry the ball around the globe to represent the monthly revolution of the moon around the earth. An observer on the globe would see the ball projected upon different objects during the revolution of the ball in its orbit. In a similar way, the moon is seen projected upon different parts of the celestial sphere on account of its movement around the earth. Unlike the eastward motion of the sun, which is only an *apparent* motion due to the real movement of the earth, the eastward motion of the moon is a *real* motion due to its actual revolution.

5. To illustrate eclipses of the moon.—(*a*) Cast a shadow of a sphere on to a screen, using a small source of light, such as a candle-flame. Notice that the shadow is circular and of equal darkness throughout.

(*b*) Substitute a lamp, with a round glass globe larger than the sphere, for the candle. Notice that the shadow on the screen is made up of two parts, an inner very dark circular patch called the *umbra*, while concentrically arranged round it is a partially illuminated shadow, forming a ring, called the *penumbra.*

6. **To illustrate an eclipse of the sun.**—Using the lamp with a large globe, cast a shadow of a very small sphere. Notice that the shadow comes to a point, as can be shown by moving the screen slowly from the sphere, when the shadow gradually becomes smaller and disappears. This is a *converging* shadow, while those of the two previous experiments are *diverging* shadows.

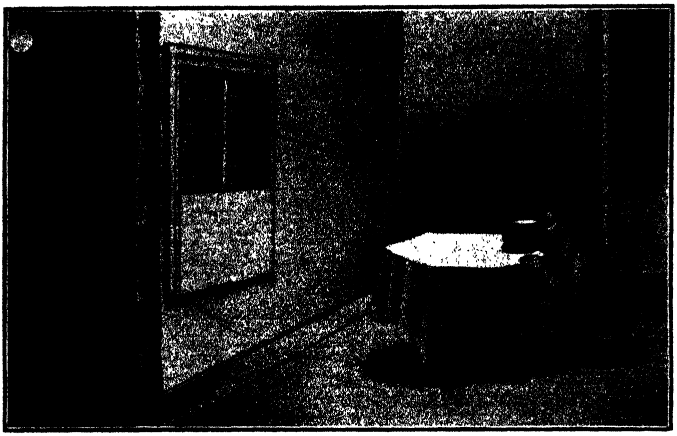

FIG. 85.—Method of ascertaining the moon's distance from the earth. If the diameter of the moon is known and the chord subtended at the shutter of the window measured, it is possible by also measuring the distance from the observer's eye to the window to calculate the distance to the moon by simple proportion. (Taken from Todd's "New Astronomy" with permission of the American Book Company, New York.)

The moon is a smaller body than the earth, revolving round it thirteen times during one revolution of the earth round the sun. Like the planet upon which it attends as a **satellite,** it has besides this motion of revolution one of rotation as well. It completes a single rotation in exactly the period of time during which it travels once round the earth. The result is that one side of the moon is never seen from the earth.

At the time when the moon appears largest, which is called **full moon,** it would seem to be the greatest of the heavenly bodies. This is not by any means actually so, the appearance being caused by the nearness of the moon to the earth. It is the nearest heavenly body.

Its distance from the earth is roughly ten times the circumference of the earth, the actual distance varying between 222,000 miles when the moon is nearest to us, or in **perigee**, and 253,000 miles when it is as far away as it can be, or in **apogee**. The average distance is 239,000 miles. The moon's distance from the earth varies because the orbit in which it travels is elliptical, as in the case of the planets. From the effect of nearness upon the apparent size of a body, the student will not be surprised to learn that the moon has a diameter of only one quarter that of the earth (Fig. 85).

Phases of the moon.—The moon travels round the earth once a month; and the interval of time between two successive full moons is 29½ days. The moon has no light of its own, but the sun is shining upon its surface continually, so that the light which the moon appears to possess is really reflected sunlight. We do not, however, always see the whole of the illuminated half of our satellite, and the consequence is that we get the phases or changes of the moon familiar to everyone.

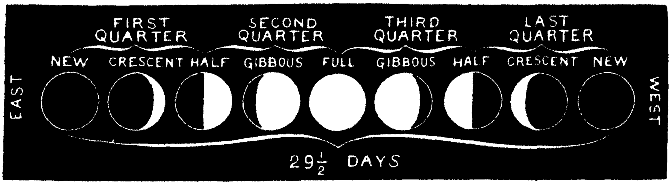

FIG. 86.—Phases of the moon during one lunar month.

At new moon the illuminated half of the moon is turned away from the earth, so nothing is seen of it. As the moon travels around the earth, first a crescent of the bright surface becomes visible. Day by day it increases in size (" waxes ") until full moon is reached, in which case the whole of that part of the moon upon which the sun is shining is seen. From this point the bright face wanes, and eventually the condition of new moon is reached again. Fig. 84 shows how these changes throughout the moon's revolution around the earth may be traced.

The moon's eastward motion in the heavens.—The continual change in the moon's position in the heavens as it revolves round the earth is made clear by noticing, night after night, which stars form its background. The *eastward* motion of our satellite then becomes very obvious. It is shown, from November 27 to December 7, 1909, by the dotted line in Fig. 87.

Rotation of the moon.—The " man in the moon " always appears to have the same expression ; in other words, the same face of the moon is always seen by observers on the earth. This is because the moon rotates on its axis in the same time that it revolves around the earth. When, for instance, the moon has travelled over a quarter of a revolution it has turned on its axis by a quarter of a rotation and so prevents the observer from seeing the new part of its surface which would, but for this compensating cause, become visible.

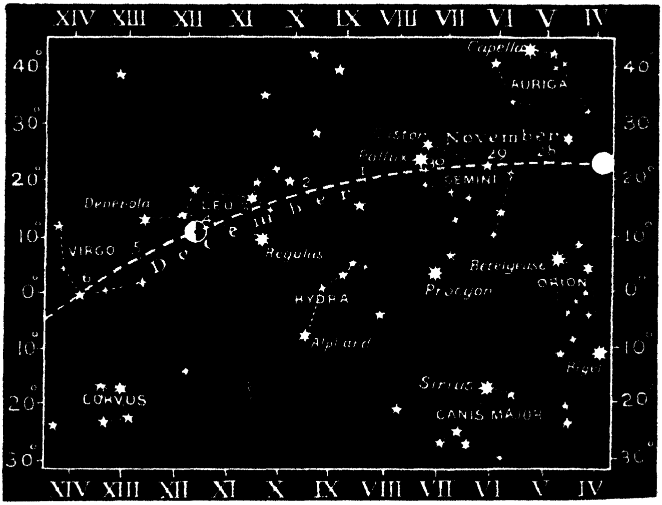

FIG. 87.—Path of the moon among the stars between November 27 and December 7, 1909.

Eclipses of the moon.—As was stated in dealing with proofs of the spherical form of the earth, an **eclipse of the moon** is the result of the earth's coming between the sun and the moon (Fig. 89). Eclipses are caused by the fact that light travels in straight lines, producing clearly-defined shadows of objects in its path.

Since the sun is the source of light, casting the shadow of the earth into which the moon travels at an eclipse, it is plain that the condition of things represented in Expt. 5, Sect. **13**, is taking place on a large scale. The moon first travels into the penumbra and is still visible though her brightness is diminished. When the umbra is reached, however, the part of the moon within it becomes quite invisible, and the appearance at this stage is represented in Fig. 88 where the circular outline of the earth's shadow is seen. Even after the moon has passed entirely into the umbra a dull red disc can still be made out. This is because sunlight is refracted by the earth's atmosphere and so made to strike upon the moon's surface, which reflects it to the earth. The coppery colour is due to the passage of these rays from the sun through the earth's atmosphere.

So far there appears no reason why a lunar eclipse should not occur at every full moon. If the plane in which the moon revolved round the earth were coincident with that in which the earth travelled round the sun, there would be an eclipse at each full moon. But the moon's orbit is inclined to the plane of the ecliptic, and it therefore happens that on some occasions of full moon the earth's satellite is above or below the shadow cast by the earth, and no eclipse occurs. At other times the moon partially passes through the umbra and what is known as a **partial eclipse** takes place. It is only when the centres of the sun, earth, and moon are in the same line that a total eclipse can occur, and this only happens when the three bodies are in the same straight line at the same time that the moon is at the points—called **nodes**—where the moon's orbit cuts that of the earth.

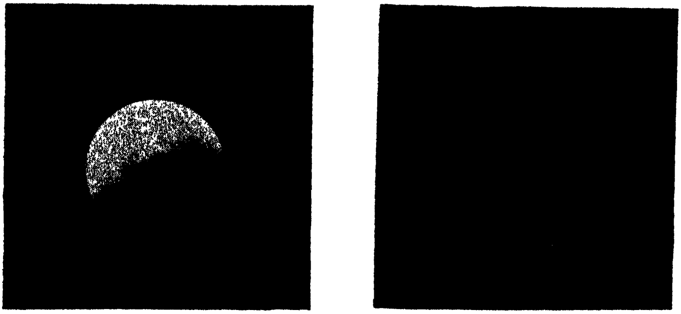

FIG. 88.—Partial and total eclipses of the moon.

Eclipses of the sun.—These **solar eclipses** occur when the moon comes between the sun and the earth, that is, at new moon (Fig. 90). Expt. 6, Sect. **13**, represents the formation of a solar eclipse. The sun casts a shadow of the much smaller moon, and the shadow sometimes falls upon the earth. But evidently the shadow will only extend over a small part of the earth's surface ; that is to say, the eclipse of the sun will not be visible everywhere upon the earth, but only at certain places where the moon is in the line between the observer and the sun.

The moon is sometimes nearer the earth than at others. **Total solar eclipses**, when the sun is blotted out entirely by the moon, occur when the moon is in perigee (nearest point to the earth) and at a node at the same time (Fig. 89). If the moon is in apogee (farthest point from the earth), and at a node at the same time, the shadow cast by the moon does not reach the earth, and consequently the appearance to an observer in the line of the shadow is different. The moon cuts off all the light of the sun except a ring of light surrounding the circle of darkness, and what is called an **annular eclipse** occurs (Fig. 91). Sometimes the moon does not pass in a direct line between the sun and the earth, in which case the sun is covered only partially, as in Fig. 90.

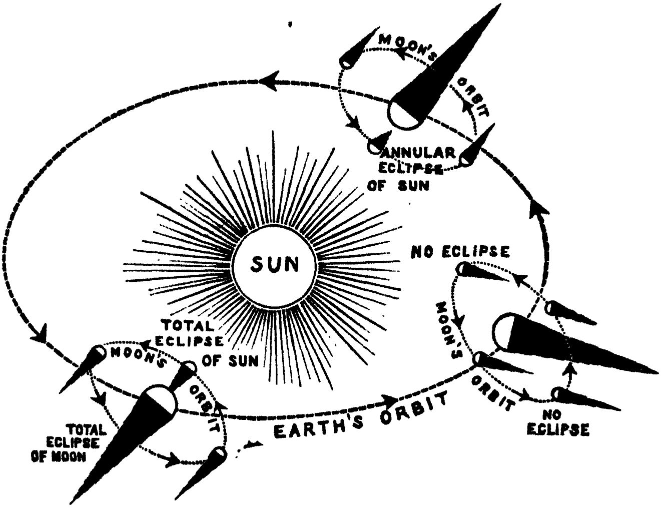

Fig. 89.—To illustrate the inclination of the moon's orbit and the causes of lunar and solar eclipses.

An annular eclipse of the *moon* cannot occur, because, whether the moon is at its nearest or farthest points, the earth's shadow at the point where the moon crosses it has a much greater diameter than the diameter of the moon.

The phenomena observed during a total solar eclipse are very striking. The moon's disc first appears on the western edge of the sun and gradually covers up the whole surface. When the sun is obscured totally there is very little light, and the bright stars can be seen as at the beginning of night. Around the sun and extending in luminous sheets and streamers for thousands of miles is seen the **solar corona** (Fig. 90). In addition to this halo, a number of red-coloured "prominences", or solar flames, may be seen shooting out from the sun behind the dark edge of the moon.

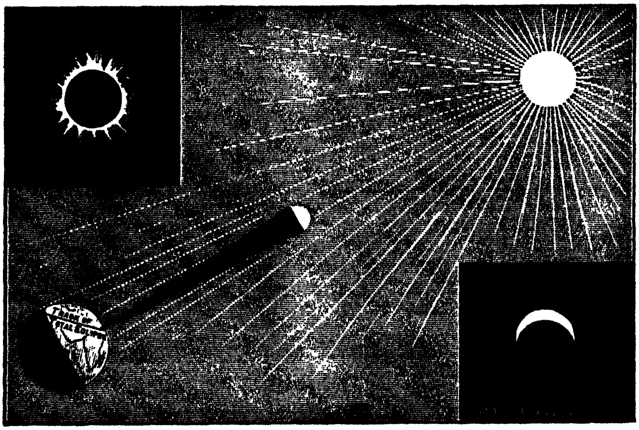

FIG. 90.—An eclipse of the sun. The inset on the left represents a total eclipse, and shows the solar corona ; the inset on the right represents a partial eclipse.

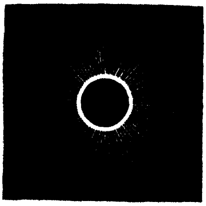

FIG. 91.—An annular eclipse of the sun.

These prominences consist chiefly of hydrogen and helium, and it is to investigate them and the solar corona that astronomers send out eclipse expeditions. The phenomena described are only observable during total obscuration of the sun, and as totality only lasts a few minutes, the opportunities to investigate them are utilised to the fullest extent. During the total eclipse of the sun on the 8th June, 1937, photographs taken from an aeroplane at 30,000 feet altitude showed that the sun's luminous atmosphere extends outwards for a million miles. They confirm the view that the general form of the corona is circular, and that the streamers are structures superimposed upon it.

EXERCISES ON CHAPTER V

1. Show how you can estimate the length of the shadow that would be cast by a stick one foot long standing vertically upon a level surface at noon (*a*) on June 21, (*b*) on December 21.

2. Explain the reason for the variation in the direction of apparent sunrise with the season, and state the nature of the change.

3. (i) The sun shines throughout the day for three days in each year on the north side of a house. What is, approximately, the latitude of the house? (ii) On a certain day the time of sunset at Greenwich was 7.42 p.m. On the same day at another place in the same latitude it was 7.52 p.m. What is the longitude of this place?

4. (i) Explain the meaning of the statement that the axis of rotation of the earth always points in the same direction. (ii) What is meant by the sun crossing the equator?

5. At a certain place on December 25, the sun attained its maximum altitude, which was 14°, at 12.5 p.m. Greenwich mean time. The declination of the sun on the day in question was $23\frac{1}{2}$° S. Find the latitude and longitude of the place where the observations were made.

6. During how much of each year is the sun above the horizon at (i) the North Pole, (ii) London, (iii) Singapore?

7. Explain fully why the sun has greater heating power in the northern hemisphere during July than during December.

8. In summer the sun *rises* earlier and in winter *sets* earlier on the Karakorams than on the Nilgiri hills. Explain this. Would it also be true to say that the sun rises earlier on (our) midsummer's day, June 21, at (*a*) Chamutong, Upper Burma (long. 98° 40′ E.), than at Victoria Point, Lower Burma (long. 98° 10′ E.), and at (*b*) Cape Comorin (long. 77° 30′ E.), than at Leh (long. 77° 30′ E.)?

When it is noon at London, what is approximately the local time at Port Said, Teheran, Kabul and Delhi?

9. Poles, of equal length, are fixed in a vertical position at the following places: Calcutta, Colombo, Aden, Durban, Penang, the Seychelles and Zanzibar. The shadows of the poles are observed at noon on June 21 and again at noon on December 21. Arrange the places mentioned in two columns according to the lengths of the shadows observed (*a*) in June, (*b*) in December.

10. On June 21 the altitude of the sun at noon is 45°, the direction south. What is the latitude and what would be the altitude at noon on December 21?

11. You are provided with an upright post, a tape measure, squared paper and a protractor. How would you use these things to determine the sun's altitude at noon, and to draw a north and south line on the ground?

12. Show by sketches the appearance of the moon in (*a*) its first quarter, (*b*) its last quarter.

13. At what times of the year does the sun rise exactly in the east and set exactly in the west? Give reasons for your answer.

14. How are eclipses of the moon caused? Why are they sometimes partial and sometimes total?

15. Explain why sunset is later in summer and earlier in winter in Scotland than in England.

16. Why do the summer days in the northern hemisphere lengthen as we go north, and the winter days shorten?

17. Give a clear explanation of the causes of the changes in the duration of daylight in various latitudes at different seasons of the year. Specially consider latitudes 0°, 30°, 60°, 90°.

18. When the declination of the sun is 10° N., in what latitudes will the noonday shadows, on level ground, be exactly equal in length to the height of the objects casting them ?

19. Explain, with diagrams, the path which the sun would appear to take from sunrise to sunset on March 21 (the vernal equinox) to men stationed at Suadiva atoll (lat. 0°), Delhi, Moscow, and the North Pole respectively.

How is it that the summit of Nanda Devi, 25,661 feet, is lit up with the sun's rays for some time before Milam village (at the foot of the mountain) receives any rays at all?

20. In what direction is the sun at midday, and where does he rise and set? What changes do you notice in these directions as the year goes on? What effects are produced by these changes?

How would your answers have to be altered if we were in (1) the Steppes of Siberia on the Arctic circle, and (2) Central Africa at the outfall of Victoria lake?

21. If the moon rises at 6 p.m. to-day, about what time will it rise to-morrow? How can you tell whether a half moon is at its first or its last quarter?

22. How would you set the gnomon or pointer of a sundial? Give your reason.

23. Give approximately the Greenwich time of sunrise and sunset, at the centre at which you are examined, on (*a*) December 21, (*b*) March 21, (*c*) June 21.

24. Explain each of the following: (*a*) How day becomes night, (*b*) how winter becomes summer, (*c*) how two places, not on the same meridian, may have different times at the same moment.

25. Describe in detail the earth's path round the sun, indicating briefly the causes of the seasons and the peculiarities of our calendar.

26. Give the reason of unequal days and nights. Show how you could calculate the length of a day in latitude 45° N. on June 21 and on March 22.

27. Arrange the following places according to the length of the day (*a*) at the end of March, (*b*) at the end of June, putting the place with the longest day first, and carefully explaining your arrangements: Alexandria, in Egypt; Colombo, in Ceylon; Akyab, in Burma; Brisbane, in Australia, and Sorabaya, in Java.

28. What facts about the moon could be learnt by carefully watching its appearance and movements each night for a month? Explain the phases of the moon.

29. Note briefly the obvious changes to be seen in the moon, as regards both shape and position in the sky, from its first appearance as a crescent until its waning. How long does the whole process take? Do we see the waxing moon rise and the waning moon set? If not, why not?

30. Account for these facts:

(*a*) The sun shines at times into a classroom, the only windows of which face due north;

(*b*) A map on Mercator's projection shows Greenland as covering almost the same area as South America, though in reality it is about one-tenth its size.

31. What is meant by the latitude of a place? Give an account of a simple way of finding the latitude of your school (*a*) on March 21 if it is sunny, and (*b*) on any clear night.

32. Why are the seasons south of the Equator the reverse of ours? Draw a diagram to illustrate your answer.

33. The highest altitude of the sun at Delhi on a certain day is 60°. What season of the year is it? Describe exactly how you would proceed to find the altitude of the sun at noon on any particular day.

34. Describe exactly what you would do to obtain experimentally the latitude of your school.

35. Explain fully the advantages and disadvantages of the introduction of "Daylight Saving" or "Summer Time". Compare their importance in (i) Colombo, (ii) Nagpur, and (iii) Peshawar, and account for the differences.

36. State the facts as to the duration of light and darkness during the six months from September to March at the following places: (*a*) the Equator, (*b*) Simla, (*c*) Iceland, (*d*) the North Pole. Explain the causes of the facts with the aid of diagrams.

PART II

LAND AND SEA

CHAPTER VI

LAND AND SEA

14. DISTRIBUTION OF LAND AND WATER

1. Ratio of land to water.—Examine a school globe and notice the great preponderance of water surface over land surface. Turn the globe so that you can see as much land as possible in one view. Where, approximately, is the centre of the " land hemisphere "? Express the answer both in words and in latitude and longitude.

Turn the globe so that you can see as much water as possible in one view. Where is the centre of the " water hemisphere "? Is it north or south of the equator?

2. The main land masses.—*Using a globe,* (*a*) Find and study the positions of the following *continents* : Europe, Asia, Africa, North America, South America, Australia. Arrange them as nearly as possible in the order of their size. (Could you do this from a map of the world on Mercator's projection? See p. 75.)

(*b*) Make a list in order of their size of the six largest ***peninsulas*** in the world, stating in each case (i) the ***isthmus*** by which the peninsula is connected with the neighbouring mainland, and (ii) the direction in which the peninsula points. With how many of the peninsulas is an island or a group of islands associated?

(*c*) Make a list, in order of size, of the six largest ***islands***.

3. The main bodies of water.—*Using a globe,* (*a*) Find and study the positions of the following *oceans* : Atlantic, Pacific, Arctic and Indian.

Arrange them as nearly as possible in order of their size, stating in each case the names and directions of the continents bordering them.

(*b*) Make a list, in order of size, of the six largest *seas* (portions of oceans more or less enclosed by land), state the ocean of which each is a part, and name the *strait* by which it is connected with its ocean.

(*c*) Make a list, in order of size, of the six largest *lakes*.

Ratio of land to water on the surface of the globe.—About 72 per cent. of the whole surface of the globe is covered with water. The actual extent of this vast expanse is estimated variously by different authorities, but for our purpose it will be sufficient to say that it is about 145 millions of square miles out of a total of 197 millions. It is not distributed equally over the whole surface of the planet; there is far more land in the northern than in the southern hemisphere. If a globe is arranged so that England is on the top, it is found on looking down upon it that a very large proportion, nearly a half, of the hemisphere seen is land, but on examining the lower hemisphere, it is found to be almost entirely, over 90 per cent., water.

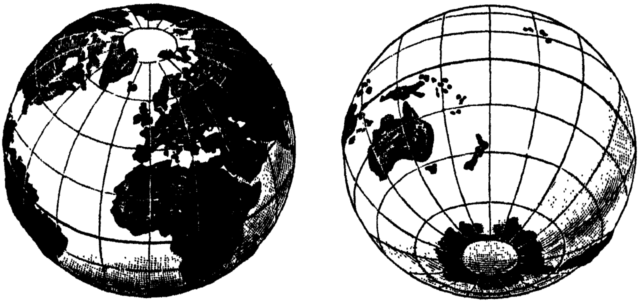

FIG. 92.—The land and water hemispheres.

The highest point of the earth is Mount Everest, 29,000 feet, on the borders of Nepal, and the deepest abyss is Planet Deep, 35,410 feet, east of Mindanao, Phillipines. The average height of the land above sea level is roughly 2400 feet, while the average depth of the ocean is 12,000 feet. If we exclude the oceanic waters and consider only the rock surface, then the **mean sphere level** is, approximately, 7500 feet below sea level and 43 per cent. of the rock surface is above and the remainder, 57 per cent., is below mean sphere level.

The continents.—The main land masses of the earth are called **continents.** It is more scientific to define their margins by the contour line of 600 feet below sea level than, as usual, by the present shore line.* *Europe* and *Asia* appear to form one continuous area, but a well-marked depression along the east of the Ural mountains shows that a comparatively slight subsidence would cause them to be separated by water—a fact which justifies the custom of regarding them as distinct continents. *Australasia* (consisting of Australia with the associated smaller islands) is sometimes regarded as an annexe of Asia to the south-east, although it properly receives continental rank. *Africa* is separated, at present, from Europe by the eastward rift of the Mediterranean Sea ; and in the " New World " *North America* and *South America* are almost separated by the Gulf of Mexico and the Caribbean Sea.

It may be noticed that the great land masses tend to be roughly triangular in shape and to taper to the south. This is seen in North and South America, Africa and India. On the other hand the oceans, while also roughly triangular, taper generally to the north. In the northern hemisphere the land masses form a nearly complete ring round the earth, and in the southern hemisphere the oceans completely encircle it. Another curious fact is that there is water at the antipodes of practically every land mass, and *vice versa.*

The areas of the continents are estimated as follows :

Europe - - -	3,900,000	square miles
Asia - - - -	17,300,000	,, ,,
Africa - - -	11,530,000	,, ,,
North America - -	9,500,000	,, ,,
South America - -	6,820,000	,, ,,
Australasia - -	3,450,000	,, ,,

The great peninsulas.—The separation of North America from South America by the Gulf of Mexico, of Africa from Europe by the

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* The Continental shelf is taken from sea level to 660 feet below sea level. Lowlands are often regarded as from sea level to 660 feet above sea level. Uplands are classed as from 660 feet to 2,300 feet above sea level. Highlands are elevated regions upwards of 2,300 feet above sea level.

Mediterranean Sea, and of Australasia from Asia by the South China Sea, is seen to be less complete if the Continental shelf is considered as part of the land. A study of the existing seaways and land bridges, or islands, in the areas separating the various continents named above, has provided evidence of the presence of earlier seas—so-called "geo-synclines" of geologists. These "geo-synclines" were nearly continuous seaways round the world at the close of the mesozoic era, nearly 60 million years ago, and included the belts now occupied by the Himalayan mountains and the ranges of Burma, Baluchistan, Persia, Asia Minor, the Alps and the Atlas mountains of North Africa. Since then great earth movements have taken place and volcanic eruptions, both in the sea floor and on land, have occurred, and gradually the mountain systems have risen out of the sea, and the distribution of land and water has gradually assumed the features we find to-day in Asia and the Mediterranean region. The same processes operated in America to produce the great mountain systems of the west coast and also the island festoons in the West Indies.

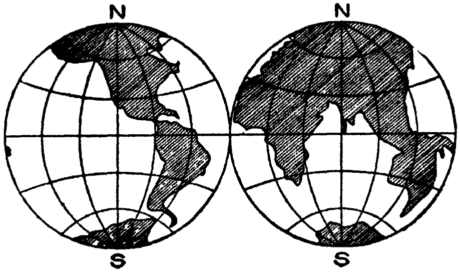

FIG. 93.—The continents with their submerged portions added (after Gilbert).

A careful study of the mountain ranges of southern Asia will show how the axes follow directly from, or are part of, certain chains of islands. The ranges of Burma sweep southward along the arcs on which on the one hand lie the islands of the Andamans and Nicobars and so through Sumatra and Java, and on the other make the backbone of the Isthmus of Kra, which connects with the Malay Peninsula.

Between these axes of elevation lies the almost enclosed Andaman sea. It is conceivable that with sufficient uplift the sea might recede and allow an isthmus from Burma to connect with Australia, and thus convert that island continent into a peninsula.*

Division into oceans and seas.—For the sake of convenience in locating the position of places on the ocean, geographers have given names indicating the relative size and nature of parts of the waters covering the earth.

There are five main divisions to which the term **Ocean** is given, they are, in order of their areas, *Pacific*, *Atlantic*, *Indian*, *Antarctic*, and *Arctic* Oceans.

The **Pacific Ocean** is the portion lying between Asia and Australia on the west, and North and South America on the east. Its area is about 67,700,000 square miles.

The **Atlantic Ocean** is bounded on the west by North and South America, and on the east by Europe and Africa. It has an area of some 34,300,000 square miles.

The **Indian Ocean** is surrounded by land in the west, north and east—Africa on the west, Asia on the north, Polynesia and Australia on the east. It extends in a southerly direction as far as the Antarctic Circle. Its area is approximately 27,700,000 square miles.

The **Antarctic Ocean** is the whole of the extent of water within the Antarctic Circle, the **Arctic Ocean** that within the Arctic Circle.

Portions of these oceans more or less enclosed by land are referred to as **seas**, such as Baltic Sea, Mediterranean Sea, China Sea, etc.

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* Professor Charles Lapworth generalised the grand features of earth (crustal) relief as a succession of folds or waves which built up the minor features. He considered that one great series of crust waves, from east to west, is crossed by a second great series from north to south, giving rise by their interference to six great elevated masses—the continents—arranged in three groups, each consisting of a northern and southern member separated by a depression. (*Brit. Assoc. Rept.*, Edinburgh, 1892, p. 699.)

Professor Eduard Suess also decided that the plan of the earth is the result of two movements of the crust—one, subsidence over wide areas, giving rise to oceanic depressions and leaving continents protuberant; the other, folding along comparatively narrow belts, giving rise to mountain ranges. These two views are thus not in agreement, but the idea of folding is common to both.

15. THE OUTLINES AND SURFACES OF LAND MASSES

1. Main directions of coast lines.—Study a map of the world on *Mercator's projection*, which (p. 75) shows shapes, though not sizes (areas), correctly. What are the general directions of the following main lines of coast: (*a*) from Florida to Newfoundland, (*b*) from South Patagonia to Pernambuco, (*c*) from Cape Colony to Baluchistan, (*d*) from Malacca to Bering Strait?

Make a list of any coast lines which are approximately (i) parallel, (ii) at right angles, to these.

Make a list of all long lines of coast running approximately east and west.

2. Eastward trend of southern land masses.—How do South America, South Africa and Australia lie with respect to North America, North Africa and Asia respectively? Note the positions of any large islands near the south ends of the continents; do they lie to the south-east or to the south-west? Note also the position of submarine ridges and reefs, especially in the Bay of Bengal and N.E. Indian Ocean. Observe the position of the ocean deeps with respect to island festoons in the western Pacific and Indian Oceans.

3. Comparative heights of land masses.—Study either an orographical map of the world or orographical maps of the continents in succession. In each continent find and make a note of:

(*a*) the positions and heights of the principal *peaks* in the Himalayas and Assam-Burmese ranges;

(*b*) the positions and directions of the orographic axes of the chief *mountain ranges*, noticing especially whether they run (i) approximately east and west, (ii) approximately N.E. and S.W. or N.W. and S.E., (iii) roughly parallel or at right angles to the nearest coast line;

(*c*) the position and extent of any *plateaux* (p. 148) and *plains*, with their estimated average heights, in the Indian Empire;

(*d*) the position and extent of any ground lying below sea level in western Asia and north-east Africa.

4. Sections across India.—From bathy-orographical maps of India draw the following sections, in the manner explained on pp. 47 and 52:

(*a*) from the Arabian Sea to the Salween river, along latitude 20° N., and from Kanchenjanga to the Sundarbans, along the meridian of Calcutta;

(*b*) from the Karakorams to Cape Comorin, along the meridian of Delhi;

(*c*) from Lhasa, in Tibet, to the Indian Ocean, along the meridian 91° E.;

(*d*) from Madras to Siam, along latitude 14° N.;

(*e*) from Colombo to East Africa, along latitude 7° N.;

(*f*) from Mangalore to Abyssinia, via Aden, along latitude 13° N.

5. Drainage areas of continents.—Taking a map of each continent separately, make a list of the principal rivers flowing into each of the oceans bordering that continent. Tabulate, for example, the European rivers flowing into the Atlantic and Arctic Oceans, the Mediterranean Sea (including the Black Sea) and the Caspian Sea respectively.

Now draw dotted lines on the map to separate the head waters of each group from those of other groups. The dotted lines are *watersheds,* and the areas into which they divide the continent may be called the *drainage areas* of the continent.

Do the same with the other continents in turn.

In each case state how far the watersheds coincide with (*a*) mountain ranges, and (*b*) political boundaries.

Directions of coast lines.—An orographical map of the world on Mercator's projection—which (p. 75) represents shapes and directions, though not relative areas, correctly—shows at a glance the main "lines of construction" of the great land masses. Among these features the most striking is perhaps the arrangement of the principal *coast lines* to run in directions approximately north-east and south-west, or at right angles to this, viz. north-west and south-east. Conspicuous among the former group are the east coasts of North and South America, of Africa (with the south coast of Arabia) and of Asia; while in a direction roughly perpendicular to this are the west coasts of North America and Peru, the north coast of South America, the north-east shore of Labrador, the shores of the Red Sea and many smaller stretches.

Another feature which is brought out clearly by such a map is the fact that the southern land masses lie a little further to the east than those with which they are associated most closely on the north. South America lies to the south-east of North America, South Africa to the south-east of North Africa, Australia to the south-east of Asia. The suggestion has indeed been made that these northern and southern lands have been brought into positions which are different to their original positions.

It is also noticeable that an island, or a group of islands, occurs near the extremity of each of the main southern land masses—a little to the east. Tierra del Fuego is associated in this manner with South America, Madagascar with Africa, Ceylon with India, and

Tasmania with Australia. The full significance of these facts is not yet understood, and we need not concern ourselves at present with the explanations which have been suggested.

The heights of the land.—The average height of the continents is estimated at only some 2400 feet above the level of the sea, but the altitude of the land varies between the 29,002 feet of the highest mountain (Mt. Everest) to land surfaces and lake basins below sea level in certain places, *e.g.* to the north and west of the Caspian Sea (which is itself 100 feet below sea level), and in Holland as well as in parts of Africa, Australia and North America. The high land forms either elevated table-lands, usually cut up by deep river valleys and called **plateaux** if they slope on all sides to lower levels, or more or less well-marked ridges of the earth's crust, called **mountain chains.**

The principal **plateaux** are :

In *Europe*, the Spanish Plateau.

In *Asia*, the plateaux of Tibet, Mongolia (almost rainless), Iran and Arabia. The best-known is, of course, the Deccan (India). It begins with a great scarp—the Western Ghats—which faces the Arabian Sea. The land surface, however, slopes eastwards to the Bay of Bengal—as is evident by the direction of practically all the rivers which rise in the Deccan.

The greater part of *Africa*, south of the Sahara, consists of the "Great Central Plateau". The best example in *Africa* is the plateau of Abyssinia (Ethiopia) with its great scarp, on the 40th meridian, facing the Gulf of Aden. From this scarp the land slopes westwards to the valley of the Nile, in the Sudan. South of the Gulf of Aden is the Somali plateau with its north-facing east to west scarp and southward drainage. It is separated from the Abyssinian plateau by a great line of fracture which can be traced through the great lakes Nyasa, Tanganyika and Victoria Nyanza, through the Plateau of Abyssinia, and up the Red Sea and the Gulf of Akaba through the valley of the Dead Sea to the slopes of Mount Hermon.*

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* The Great Rift Valley of Africa was believed to be due to a tearing apart and subsidence of a strip of the earth's crust, and the fracturing was thought to have been caused by tensional forces. There are many who now accept the data, recently obtained from various places in the Great Rift Valley, as proving compressive, shearing stresses to have caused the fracturing of a true continental area.

In *North America* only the high land of Mexico is flattened sufficiently to receive, usually, the name of plateau, and in *South America* only that of Bolivia.

The **mountain ranges** lend themselves more readily to classification. In the *Old World* the mountain chains of the northern continents, for the most part, run east and west; this is exemplified by the Pyrenees, the Alps, Carpathians, Caucasus, Himalayas and Altai Mountains. The Atlas range of North Africa may be included with these. The Pennines, Scandinavian Mountains, Apennines and Ural Mountains, as well as the Aravali range and the Eastern Ghats in India, all of which form an obvious exception to the rule, are now of minor importance, and much older in date of origin (Chapter IX). In *Africa* and *Australia*, on the other hand, such ranges as are at all well defined run north and south.

In the *New World* the mountain ranges, almost without exception, take a north and south direction. The Rockies and Appalachian Mountains of North America, and the Andes of South America show this conspicuously.*

Plains—the more or less flattened lowlands—perhaps occupy a greater area of the land surface of the earth than plateaux and mountain chains together, and the student should remember at least the positions of the largest expanses. Among these may be mentioned the Great Lowland Plain of Europe; the Great Siberian Plain, and the plains of China, India and Irak (Mesopotamia) of Asia; the Great Central, the Northern, Gulf and Atlantic Plains of North America; and the Selvas of the Amazon in South America. These areas form on the whole the most fertile part of the earth's surface, and are watered by long, slow and winding rivers, which constitute the principal means of communication, and have in many cases actually laid down the material of the plain, as sediment washed down from the high lands in which they take their source.

It will be understood that the terms plain and plateau are purely relative, and that it is in many cases a matter of opinion whether one word or the other is the more appropriate. Even a mountain can only be defined in relative terms as high land with an insignificant summit area.

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* As previously mentioned, the mountain chains of Asia, Europe and North Africa, which have a general east to west trend, as well as those along the western side of North and South America, which run north and south, occupy belts which at an earlier geological period were seaways or geo-synclines. There seems to have been no north and south seaway across Africa, or else, perhaps, the line of the Rift Valley might now be a great north and south trending mountain chain.

Drainage areas of continents.—It is an easy and instructive exercise to trace out the main watersheds of the continents, and so to divide the land into " drainage areas " which show what proportion of it contributes to each of the various adjoining oceans.* Such an exercise shows that watersheds coincide in general with mountain ranges, which have determined many political boundaries. It also emphasises the nature of certain lakes and inland seas which, lying in a depression having no outlet to the sea, and receiving the drainage of the high land surrounding them on all sides, act as evaporating pans, and concentrate the river water to a sort of brine, which increases in strength continually. Such **salt lakes** are naturally found chiefly in areas where scanty rainfall is accompanied by great evaporation. The Great Salt Lake in Utah, the Dead Sea, and the Caspian are well-known examples of such lakes, and the **salt deposits** at Salton in the California desert, and in the desert regions of Turkestan, Patagonia, and China, are no doubt to be referred to a similar origin.

Sambhar lake, in Rajputana, is a good Indian example of a salt lake in a desert region. A careful examination of the mode of origin of this salt lake led Sir Thomas Holland to believe that the salt was carried inland by the breeze which blows in from the Arabian sea. His views were supported by investigations carried out by Dr. W. A. K. Christie, and it is now accepted that the salt in Rajputana is **wind-borne,** or **cyclic salt,** as distinct from that leached from the rocks and concentrated in an enclosed sea or lake. However, in both cases the salt is concentrated in the lake basin by being carried there by flowing water, which is subsequently wholly or partially evaporated by the sun's heat. Studies of the great salt deposits of ancient formation, such as those of Stassfurt in Germany, the Punjab Salt Range in India, those of Namak Ab in northern Afghanistan, and various places in Persia, show that these are due to the gradual evaporation of large seas, or almost separated seas, such as the gulf of Karabaghaz in the Caspian, where an abundant supply of salt water is available, and not to accumulations of cyclic salt. Also there is evidence that the salt-bearing rocks of Cheshire and Worcestershire in England were formed under marine conditions of the same kind as those of Germany, Persia and the Punjab.

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* It is estimated that 27 per cent. of the rivers of the world drain into the Pacific and Indian Oceans, 22 per cent. have no outlet to the sea, and no less than 51 per cent. are tributary to the Atlantic (Avebury).

16. THE CONTOUR OF THE OCEAN FLOOR

1. The ocean floors.—*Examine a bathy-orographical map of the world.* (*a*) How many different depths are shown on it? In what parts of the world are there the greatest extents of shallow seas? Where is the sea deepest? Which coast lines would be most affected by an elevation of 600 feet? What would be the chief changes thus produced? Which coast lines would be least affected?

(*b*) What amounts of elevation of the ocean floor would join (i) British India to Ceylon, (ii) Madagascar to Malabar, (iii) Burma to the Andamans, (iv) Australia to Asia, (v) Europe to Africa?

(*c*) From the information supplied by the map write an account of the contour of the floors of the Atlantic, Pacific and Indian Oceans, and draw sections across the Indian Ocean (i) along the equator, (ii) from Bombay to the Antarctic.

(*d*) *The Continental Shelf* is defined as the sea bottom between the shore and the 100-fathom line. Do the British Isles stand on the edge of a continental shelf? What is the situation as regards the sea floor between Australia and Asia?

2. The seas of Asia and Europe.—*Examine a bathy-orographical map of the world.* (*a*) How does the land abutting on shallow seas differ in height from that facing deeper seas? Give examples. What is the greatest depth shown on the map?

(*b*) Draw a map of the outline of Asia and Europe as it would be if the land rose 600 feet. Where would there be the least alteration in the coast line? Where most? What *rivers*, now separate, would be likely to join together? Where would they reach the sea? What new *lakes* would be formed? What would the present *estuaries* become?

(*c*) Write a description of the topography of south-eastern Asia as it would be after an elevation of 6000 feet.

(*d*) What would be the principal changes in coast line if southern Asia were depressed 600 feet? What would then become of such river valleys as those of the Euphrates, Indus, Ganges, Irawadi and Salween? What name would then describe them? Where, in the present coast line of Europe, are there signs of " drowned river valleys "?

3. Deposits on the ocean floor.—Compare the maps Figs. 95 and 97, and state as nearly as possible the range of depths at which the deposits mentioned in Fig. 97 occur. Compare the terrigenous (*i.e.* land-derived) deposits with the extent of the continental shelf, and study particularly the distribution of globigerina ooze and red clay in the Indian Ocean.

Modes of determining depths of the sea.—Before the Great War it was usual to find the depth of the sea, when this did not exceed about 1000 fathoms, by "**heaving the lead**"—that is, by dropping from a ship a leaden weight attached to a line which was marked with differently coloured strips of bunting at intervals of every 50, 100 and 1000 fathoms—and noting the length of line which had run when the lead touched the bottom. The lead was armed at its lower end with a thick coat of tallow, to which a sample of the material forming the sea floor stuck and incidentally proved that the bottom had been reached.

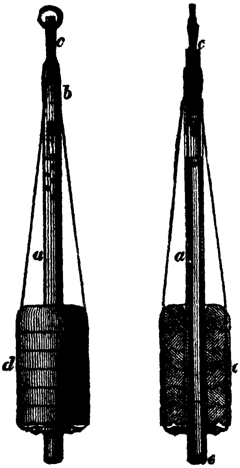

FIG. 94.—Deep Sea Sounding Apparatus used by the *Challenger*.

With greater depths than 1000 fathoms, however, the method just described was found to be untrustworthy for various reasons; thus, the line was liable to sag or be deflected by submarine currents and so to register too great a depth, even if the lead sank rapidly and vertically to the bottom; a lead heavy enough for this might be too heavy to be drawn up without breaking the line; also there was often no clear indication when the bottom had been reached, since the line might continue to run out afterwards. In order to obviate these sources of error, which had vitiated some of the earlier observations, the apparatus shown in Fig. 94 was used by the observers in the famous *Challenger* expedition, to which we owe so much of our knowledge of the ocean depths. The apparatus was so designed that

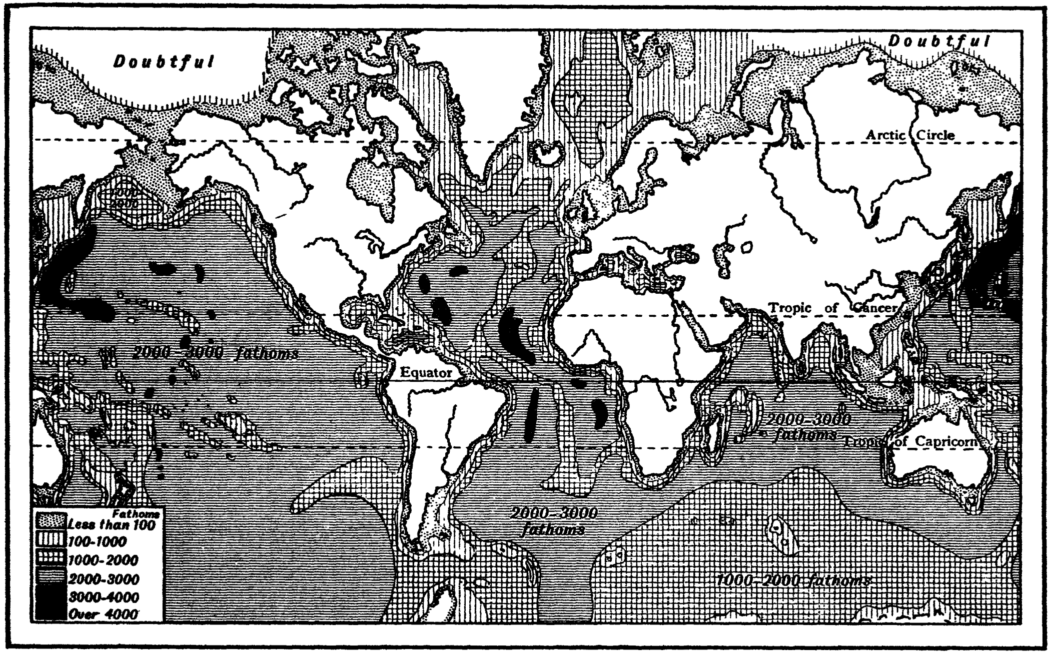

FIG. 95.—Map showing varying depths of the ocean. The 100 fathom line marks the edge of the "Continental Shelf".

when it came in contact with the sea bottom the tube *e* penetrated into the material on the floor, filling the lower end with a specimen which valves prevented from escaping, and the sling carrying the heavy iron weights *d* was detached, the weights themselves being left behind.

During and after the Great War, a new way of measuring the depth of the sea from a ship was introduced and is replacing the older and cruder methods described above. This is called **echo sounding**.

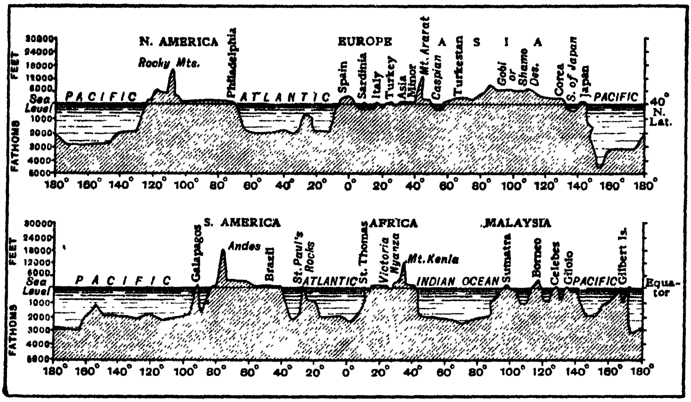

FIG. 96.—Approximate sections round the earth, showing elevation of the land and depth of the sea along the parallel of 40° N. latitude (upper figure) and the equator (lower figure). Vertical scale greatly exaggerated.

The principle of echo sounding is simple ; a sharp noise is made at the surface of the water by the transmitter—essentially a hammer striking on a plate fixed to the hull of the ship. The sound wave travels through the sea water and is reflected from the sea bottom. The echo is received at the surface by a microphone, and the time taken between the transmission of the sound and the reception of its echo is accurately registered. The velocity of sound in sea water is known, and therefore the distance (twice the depth) through which the sound has travelled in the time can easily be calculated. The echo of such a sound only affords information of the *average* depth of the sea below the ship. An echo from one particular point of the sea bottom can be obtained, however, by transmitting a sound of very much higher pitch, since this can be sent, as a narrow " beam ", in any direction. In this way it is possible in shallow water to locate irregularities in the depth caused by the presence of wrecks, projecting rocks, etc. Echo sounding has the advantage over other methods that it can be carried out rapidly in deep as well as in shallow waters, and also whilst the ship is travelling at full speed.

Results of soundings.—Atlantic Ocean.—Deep-sea soundings provide data for the construction of sections across the ocean, and enable us to obtain almost as good an idea of its form as if we could drain off the water and walk over the sea floor.

In the case of the North Atlantic, from the west coast of Europe to the east coast of North America (Fig. 96), there is a gradual slope from the land into the sea ; the inclination is nowhere " more than one in twenty-five, or that of a hill of moderate steepness ". The depth increases after we get two hundred miles from the Irish coast to about two thousand fathoms, and remain between two and two and a half thousand fathoms for some distance, until the floor begins to rise again into a kind of submarine table-land of a thousand miles in width, over which the depth of the water is rarely more than fifteen hundred fathoms and generally nearer one thousand fathoms. When the "**telegraph plateau**", as it has been called, has been passed, the same differences in depth are experienced, though in the reverse order ; the water first gets deeper again down the western edge of the submarine table-land and in due course the floor rises again by easy gradations into the Newfoundland bank.

The telegraph plateau extends in a northerly and southerly direction throughout the Atlantic Ocean (Figs. 95 and 96), and names have been given to it in different latitudes. Thus, north of the equator

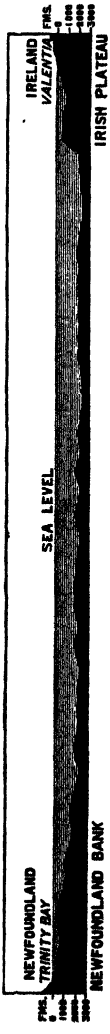

FIG. 96A.—Section of the Atlantic Ocean between Newfoundland and Ireland. Vertical scale about 20 times horizontal scale.

it is called the "Dolphin Rise"; while south of the equator it is spoken of as the "Challenger" ridge, the intermediate portion going under the name of the "connecting ridge". The student is recommended to examine carefully the contours of the ocean floors in Fig. 95, and to picture what their appearance would be if the water could be removed and a bird's-eye view of the floors obtained. The absence of such irregularities as mark the surface of the land is very striking. The ocean effectually prevents the atmospheric agencies, which are so active in sculpturing the land into its endless variety of hill and dale, from causing any similar wasting away of the sea floor. The sea floor is monotonously level. The only abrupt elevations from its even surface occur in the case of oceanic islands, which rise precipitously, and, in the absence of the waters above, which constitute mountains. This is clearly brought out in Fig. 96, where the submarine mountain, the uncovered peak of which forms the island of Galapagos, is seen towering up through more than 3000 fathoms of water and attaining a total height of 20,000 feet, rivalling that of the volcanic mountain Chimborazo.

There is thus in the Atlantic a more or less median table-land with a deep valley on either side. In some one or two parts of these valleys decided hollows occur. The first of these "abysses", lying near the Virgin Islands, has a depth of 4560 fathoms. Another lies to the south-east of North America, between the West Indian Islands on the south and the Bermudas on the north. The soundings here reveal a depth of 3875 fathoms or upwards of four miles. The third occurs in about the same latitude on the other side of the ocean, to the west of the Canary Islands, and its depth is about 3150 fathoms. A fourth depression has been found in the South Atlantic, roughly near the middle of the ocean between the east coast of Brazil and the island of St. Helena. The average of all the soundings which have been made in the Atlantic works out to about 2000 fathoms.

Pacific Ocean.—The Pacific is a deeper ocean than the Atlantic, its average depth being about 3500 fathoms, though in some places much greater depths have been reached. Thus, off the Ladrone Isles (latitude about 15° N., longitude about 152° E.) a measured depth of 4575 fathoms, or about five miles, has been recorded; off the Kurile Islands, between Japan and Kamtchatka the depth has been found to be 4655 fathoms. H.M.S. *Penguin* in 1895 found near the Kermadoc Islands a depth of 5155 fathoms.

Over several submarine table-lands the water does not exceed a depth of 2000 fathoms. One of these stretches in a north-westerly direction from the coast of Chile towards the depression near the Ladrone Islands ; another of lesser extent occurs to the south-east of the Australian continent, and it is upon it that New Zealand is situated. The islands of the Malay Archipelago rise from a third, which occupies the area between the south-eastern portion of Asia and Australia. The Pacific Ocean, in fact, presents many remarkable irregularities, a good idea of which will be obtained by looking at an ordinary map and bearing in mind what has been said about islands which occur dotted over the great expanse of water constituting the ocean.

There is no feature of exceptional interest about the **Indian Ocean.** Its average depth can be taken as about 2600 fathoms. So little precise knowledge of the other oceans is available that no special reference to them is necessary.

Marine deposits.—Samples of the materials covering the sea floor, obtained during soundings, show that the nature of the deposits varies with the depths at which they occur. To quote Dr. J. J. H. Teall, *Natural Science,* March 1892 : " Proceeding outwards from the shore, we first meet with the variable deposits of the littoral and shallow-water zones. Banks of sand heaped up under the influence of tidal currents follow, and wide stretches of mud in the deeper and quieter regions. Here and there occur local accumulations of shells and shelly *débris.* Near the 100-fathom line blue muds are found, and as these are followed down the continental slope, they merge, near its base, into globigerina ooze—a deposit which extends with wearisome monotony over immense areas. As we descend into the abysses of the ocean, to depths exceeding 2500 fathoms, the globigerina ooze passes into " grey " ooze, and this again into red clay—the most widely distributed of all the deep sea deposits." This is illustrated (Figs. 95 and 97) in a striking manner in the case of the Atlantic, where the areas covered by red clay correspond closely with the positions of the abysses. Again, the

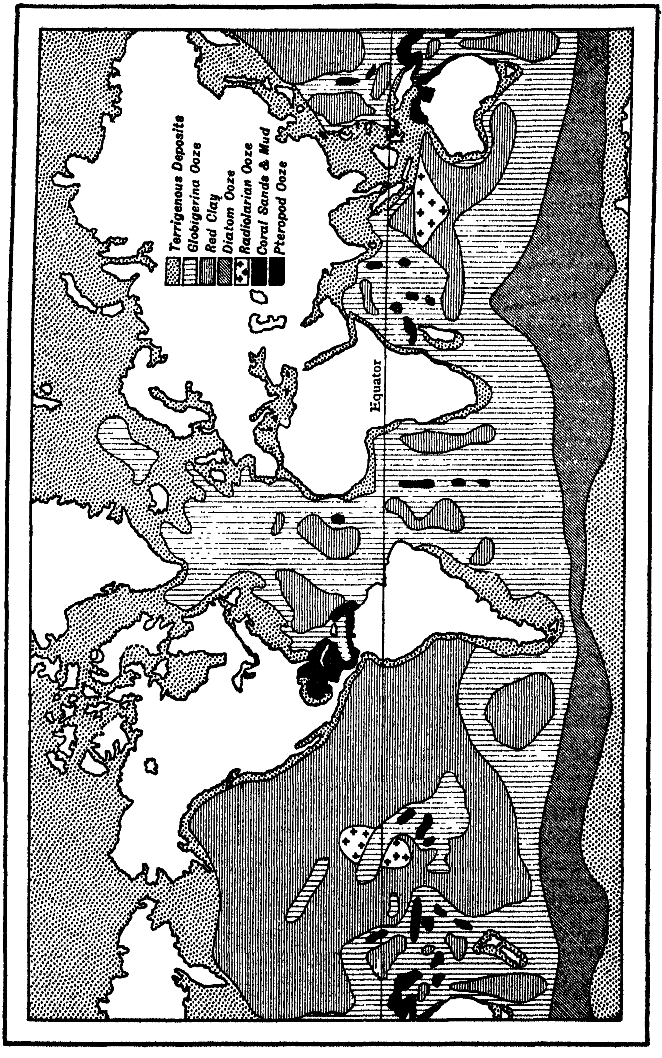

FIG. 97.—Distribution of submarine deposits.

terrigenous or land-derived deposits are seen to occur chiefly between the shore and the 100-fathom line.

It has been assumed that the deposits in the deepest parts of the ocean contain no materials derived from land and this supports the belief that while many parts of the earth have been alternately buried beneath the sea and elevated to form dry land, as in the case of geo-synclines, others have remained permanently submerged, such as the abyssmal areas of the oceans, or have been permanently dry land, such as most of Africa and the Indian Peninsula.

Depths of the Indian Ocean.—The study of the contours of the ocean floors becomes most interesting when applied to the seas of north-west Europe or of south-east Asia (Fig. 98). The British Isles are essentially a part of the European continent, which really extends along the shallow sea bottom to the 100-fathom line skirting the west of Ireland and Scotland. Beyond this line there is a sudden drop to the depths of the Atlantic. Thus the British Isles are often said to stand on the edge of a continental shelf.* In the case of southern Asia—particularly the Arabian Sea, the Bay of Bengal, and the related waters of the Indian Ocean—there is no marked land shelf, and the 100-fathom line, in most places, is roughly parallel to the coast—except along the zone between Asia and Australia. There is evidence of a submerged ledge on the line trending southwards through the coral islands of the Laccadives and Maldives to Suadiva Atoll. Ceylon is definitely part of the same platform which constitutes the Indian peninsula, but there are gulfs even at the 100-fathom line below the Gulf of Manaar and the Laccadive sea.

The island festoon of the Andamans and Nicobars is clearly part of an axial line which joins the Akyab coast of Burma with that of southern Sumatra, and marks a zone of elevation both on the lands mentioned and along the sea floor. This Sumatra-Burmese arc very definitely separates the Bay of Bengal from the Andaman sea basin. The silt of the Irawadi and Salween rivers is deposited in

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* "Landscape in History," p. 130 (Macmillan). Sir A. Geikie says: "If the west of Europe were elevated 200 feet—that is, the height of the London Monument—the Straits of Dover, half of the North Sea, and a large part of the English Channel would be turned into dry land. If the elevation extended to 600 feet—that is, merely the united heights of St. Paul's and the Monument—the whole of the North Sea, the Baltic, and the English Channel would become land. There would likewise be added to the European area a belt of territory from 100 to 150 miles broad, stretching to the west of Ireland and Scotland.

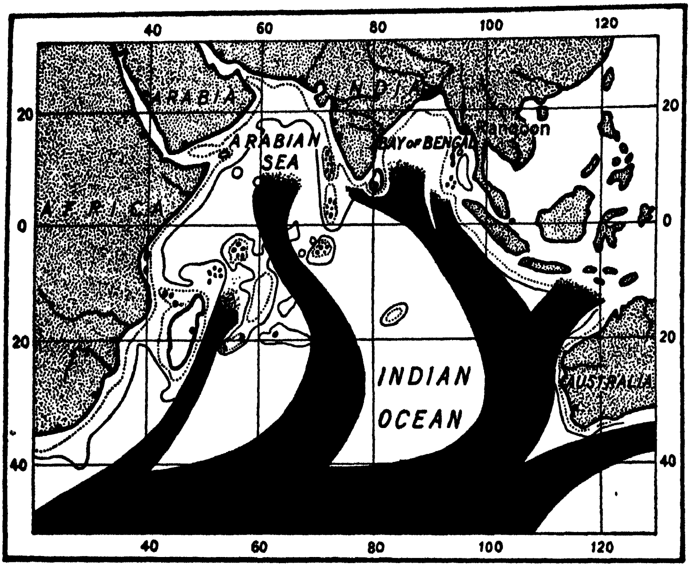

FIG. 98.—Antarctic Currents in the Indian Ocean. Chart showing rough configuration of sea floor in the Indian Ocean and the probable distribution of the bottom-drift of the cold antarctic water. (After R. B. Sewell, *Memoirs, Asiatic Society of Bengal*, vol. ix, No. 2, Pt. II, 1925, chart VI, p. 48.)

the Andaman sea basin, which is relatively shallow along the Burmese coast. The floor of the Bay of Bengal appears to slope gradually from north-west to south-east, except at the mouths of the Ganges, off the Sundarbans, where there are shoals and the curious " gully " known as the " Swatch of No Ground " * at the mouth of the Haringhata river.

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* The origin of the " Swatch of No Ground " is ascribed to a seaward undertow which is believed to be operative during the south-west monsoon. It is also claimed to be due to an inward sea floor current, which is known to be present during the north-east monsoon. As deposits of Pteropod ooze have been found in the " Swatch of No Ground ", and these delicate organisms must have been swept in from the deep sea to the south, the proof for the inward sea floor current seems good.

The " Swatch of No Ground " divides the banks south of the Sundarbans into two—an eastern or Megna section and a western or Matla section. The head of the gully is 20 miles from the land and the floor has been traced for nearly 70 miles in a south-west direction. It is 20 fathoms deep at its head, but sinks rapidly to 120 fathoms; is about 450 fathoms in the middle and 600 fathoms at its seaward end. It is 7 to 12 miles broad, with extensive shoals on either side. It would appear to be an under-water estuary for the re-combined waters of the delta rivers after they have spilled on the seaward side of the Sundarbans.

The coast line of India.—A study of the Admiralty charts of the north Indian Ocean shows that banks exist which, with sufficient elevation, would separate the Arabian Sea basin from the southern ocean. It has long been accepted by geologists that at a very early period, when the coalfields of India were being formed, there was a land connection of some kind with South Africa. At a much later date, when the lava flows which cover the Deccan were being poured over the Peninsula, there was a great gulf, opening northwards, over Somaliland, Persia and southern Afghanistan. It is not possible to say with certainty whether this sea extended southwards into a great south ocean, but some kind of land barrier appears to have persisted. At a later date still when the Himalayas had already appeared as a mountain chain, from what had previously been a festoon of islands, open sea was established between India and South Africa, but land, with large sluggish rivers, was present in Afghanistan and across Persia with Arabia and Africa, and the present coast lines of India were rapidly formed by the regression of a sea over parts of Assam and Burma.

The British coast line.—It needs but a slight exercise of the imagination to picture the result which the subsidence of the land region which now forms the Continental Shelf of western Europe must have had upon a mountainous area already cut up by deep river valleys. In the case of the British Isles and adjacent areas the encroaching sea would cover the low-lying plains and thus form the North Sea, the Irish Sea and the English Channel. The sea would wind up the valleys, converting their mouths into estuaries and

firths * and upland lakes near the coast into sea-lochs or **fjords** distinguished by remaining shallower at their mouths than inland; the result would be a highly indented coast line. There can be no doubt that the characters of the western seaboard of Scotland—as contrasted with the more uniform outline of the east coast of England—are chiefly due to its greater subsidence, after the harder western rocks had been sculptured already into mountains and valleys by the more rapid rivers. The rugged character of the coast line—already marked when the present level was reached—has been subsequently accentuated by marine denudation in the manner to be described in Chapter X.

Similar "drowned river valleys" occur in many parts of the world, and are easily recognised on maps. They seem to indicate subsidence within recent geological times, and the regular contour of coasts recently elevated is equally characteristic. Both types are well shown, for example, on the west coast of North America, the signs of subsidence being obvious north of lat. 48°, and those of elevation southward. Other excellent illustrations of drowned river valleys are the fjords of Norway and the straits of Greece, while the islands of the Aegean Archipelago are as certainly the summits of mountains which formerly were part of the mainland. There is no doubt that the mountain ranges of Burma are continued southward, on the west through the island festoon of the Andamans and the Nicobars to Sumatra, and in the south through the Mergui Archipelago to the Malay Peninsula. These features suggest a regional subsidence in that part of the Bay of Bengal known as the Andaman Sea. However, the tectonics of this area are more complicated than a simple subsidence; nevertheless, the topographical features are excellent imitations of what happens in a sinking region.

Comparison of the height of continents with depth of oceans.—In measuring the height of any place it is customary to speak of its height above **sea level,** using the level of the ocean as a datum line. Every one knows, however, that the rise and fall of the tides causes an alteration of its level near the land twice each day. The Ordnance Survey authorities arranged that, so far as the maps of Great Britain are concerned, **"sea level" shall be the mean height of the sea between high- and low-water mark at Liverpool.** But this is not the only starting-point which is used; the Trinity House authorities measure heights from the high-water mark at London Bridge. Here in India, as already explained on p. 40, the datum level for all heights on the land is low-water of spring tides at Karachi. It is officially known as "Indian spring low-water mark", and is the

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* An estuary is the wide lower part of a river where it becomes tidal and its water grows more salt towards the sea and this saltiness is very marked between high and low tide.

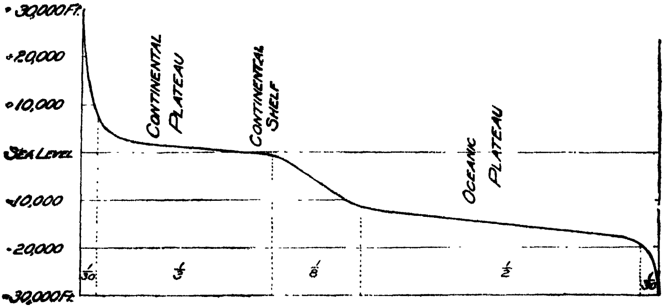


FIG. 99. Generalised profile showing relative areas of the earth's surface at different heights and depths.

plane of reference in use by the Survey of India. The datum used on Admiralty charts, founded on surveys by ships of the Royal Navy, is the same, *i.e.* level of Indian spring low-water, where the diurnal inequality of the tides is considerable, but where the diurnal inequality is small the level of mean low-water springs is adopted.

The mean average height of the continents has been estimated at 2400 feet above sea level; that is, if the mountains were all levelled and the valleys filled up, this would be the height of the land thus formed.

The mean average depth of the oceans can be put at about 12,000 feet below the sea level. The height of the highest mountain is about 5½ miles, and the greatest depth of the ocean is nearly 6½ miles. This at first appears a very great height and depth respectively. But the radius of the earth is 4000 miles, and if the distance from the top of the highest mountain to the bottom of the deepest abyss in the ocean is taken, a length of twelve miles only is obtained, or, roughly, $\frac{1}{333}$ of the total radius.

By instituting a comparison of the average height of the continents with their total area, which can be taken as roughly 52 millions of square miles, or of the average depth with the total area of the oceans, which is approximately 145 millions of square miles, the student will be impressed with the insignificance of the land elevation and with the comparative shallowness of the oceans.

Variations in sea level.—For convenience in making vertical measurements, it is assumed that the surface of the sea—adopted as zero level—is everywhere the same distance from the centre of the earth, and that any change in the height of a given place above, or in its depth below, the sea level is due to movements of the land. Both these assumptions are quite well known to be only approximately true (p. 93). Apart from the slight flattenings of the surface in polar and other regions (p. 88), the sea level is modified locally by various circumstances, *e.g.* it is higher round a mountainous coast than in the middle of the ocean, owing to the attraction of the land mass. It is estimated by gravity experiments that the sea level near Colombo is 300 feet nearer the centre of the earth than is the sea level at Karachi. Yet, owing to the influences operating on the water in a bubble tube, spirit-levelling operations would prove the sea level the same in these places. It has been suggested that the level must be permanently raised in some regions and depressed in others by the continuous action of prevailing winds and ocean currents. There are numerous examples, such as the destructive storm waves in the Sundarbans after the passage of a northerly cyclone up the Bay of Bengal, to prove the heaping up of waters by the action of strong gales. Lastly, it has been argued that there is some evidence that certain " raised beaches " owe their present height above sea level not to elevation of the land, but to subsidence of the sea caused by a sinking of the ocean floor, but such cases are hard to prove in a satisfactory way.[*]

[*] There is a raised sea beach on the west or seaward side of Bombay island, while a submerged forest occurs on the east or harbour side. This proves movement of the land alone, either in opposite directions along a north and south line of fracture or faulting, or perhaps a tilting of the island.

EXERCISES ON CHAPTER VI

1. Explain carefully the meaning of the terms *mountain, hill, plain, plateau* and *pass*. Mention any examples which occur to you of (*a*) a *range* of mountains, (*b*) a *group* of mountains, (*c*) a range of hills on a plateau and (*d*) a great mountain pass.

2. Give three examples of salt lakes, and explain why they are salt.

3. The coast line of many countries is in some parts much indented and in others unbroken. How does the country inland from the one kind of coast usually differ from that inland from the other? Give examples.

4. What instances do you know of dry land at a lower level than that of the sea? How do you account for them?

5. Describe the form of the deep-sea bottom as compared with that of dry land.

6. Describe the form of the floor of the North Atlantic. How do the deposits formed in the centre of the ocean differ from those formed on its margin?

7. What conditions lead to the formation of salt lakes, and what deposits would you expect to find in them?

8. What parts of Europe *or* Australia *or* North America are not drained by rivers flowing to the sea? State the nature of the climate of these regions in the continent selected, and name and describe very briefly the chief river of their inland drainage area.

9. What do you mean by a *natural* region? Taking any continent you like, subdivide it into natural regions.

10. Compare the coast lines of western India and that of Madras as well as the coast of Lower Burma. Explain why they differ so widely in their conformation.

11. What exactly do we mean by the term " salt lake "? In what regions of the world are salt lakes found? How are they formed? Name examples of lakes which are very salt, and of others which are only slightly brackish.

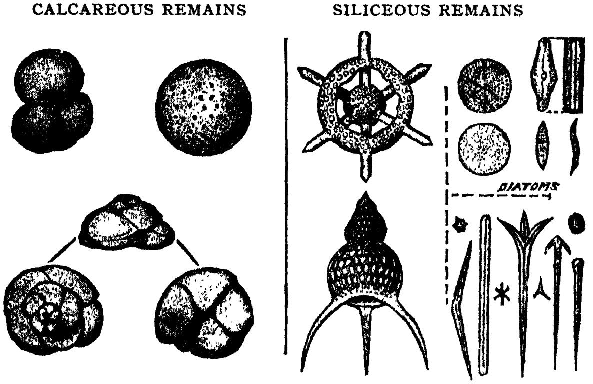
12. To what circumstances do you attribute the existence of the following?
(*a*) The island festoon of the Andamans and Nicobars.
(*b*) The smooth outline on the south coast of Arabia.
(*c*) The mountain chain of the Himalayas.

13. If the land rose 600 feet, what changes would take place in the geography of north-western Europe?

14. Describe briefly the disposition of land and water in the southern hemisphere, and give some idea of the difference in the relative amount of land and water to be traversed by men going round the world (*a*) at the Equator, (*b*) at the Tropic of Capricorn, (*c*) at Latitude 60° S.

15. What are fjords? Where do they occur and how do you suppose they have been formed?

16. Contrast the form of the eastern with that of the western coasts of Great Britain, and account for the differences as far as you can.



Foraminifera *Radiolaria* *Sponge spicules*

FIG. 100.—Typical remains found in deep-sea deposits.

CHAPTER VII

RIVERS AND GLACIERS

17. WATER AS A TRANSPORTING AGENT

1. Dissolved and suspended matter in water.—(*a*) During a heavy shower collect a glassful of rain water, and also one of the water flowing along a gully or gutter. Allow the second sample to stand, and notice the manner in which suspended particles of sand and mud settle to the bottom. How do the upper layers of the deposit differ from the lower layers? Does the water rapidly become quite clear? If not, filter it through filter, or blotting, paper in a funnel in the manner shown in Fig. 101. Similarly, filter a little of the rain water if necessary, until both liquids are quite clear. Label the vessels containing them. Can you see any difference between the two filtered liquids?

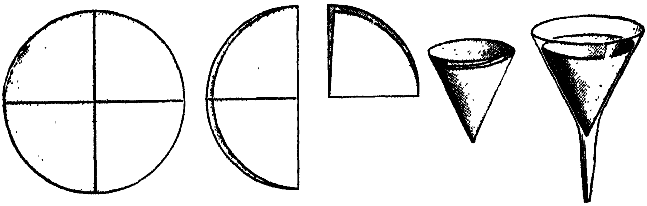


FIG. 101.—Method of filtering through filter-paper in a funnel.

(*b*) Pour any convenient measured volume of the clear rain water into a porcelain dish, or saucer. Into a second dish, or saucer, pour an equal volume of the filtered gutter water. Put the dishes over boiling water so that the steam will play on the outsides of the dishes and cause the contained water to evaporate without spurting (Fig. 102). When all the water in the dishes has disappeared, examine the residues, if any, left in them. Do the residues differ in appearance, or amount, in the two cases? How do you account for the differences? If a delicate balance is available, weigh each dish with its residue, then clean and dry the dishes and weigh each of them again, and obtain, by difference, the weights of the residues.

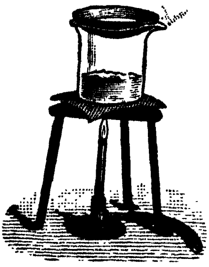


FIG. 102.—Simple water bath.

2. Loss of weight of bodies suspended in water.—(*a*) Suspend any convenient object, say the glass stopper of a bottle, with thread, from the hook to be found over the pan of a laboratory balance. Weigh the object, and then, using a wooden bridge, arrange a glass of water so that the object is immersed in the water. Do the weights in the other pan still balance it? If not, find the difference in weight which is caused by immersion of the body in water. What proportion of the weight is "taken off" by the water?

(*b*) Compare the effort required to lift a heavy weight (i) in air, (ii) under water.

3. Carrying power of running water.—When water is flowing freely along a gulley or gutter, collect samples from various points at which the flow differs in rapidity. Find out, by examining the deposit, whether the solid particles carried by the water differ (i) in size, (ii) in amount, according to the speed of the current.

4. Line of maximum velocity of a stream.—(*a*) Into a wide test tube pour glycerin to the depth of an inch, and stir it vigorously with a rod until it contains an abundance of small air bubbles. Then slope the tube so that the glycerin flows in a slope stream. Compare the rates of flow—as made clear by the suspended bubbles—at the surface, the sides and the bottom of the stream of glycerin. Repeat the experiment several times and notice whether the motion of the air bubbles is always parallel to the general direction of flow.

(*b*) (*Outdoor work.*)—When rowing upstream on a river, compare your rate of progress in midstream with that near the bank. Notice on any of the large Indian rivers—the Brahmaputra or the Ganges—how the small boats sail upstream close inshore, and how they frequently secure a tow along the banks rather than row upstream against a strong tide.

5. Measurement of velocity. (*Outdoor work.*)—Provide yourself with a number of corked bottles, each suitably weighted (by gravel or lead shot in it) and carrying a flag at the top. Measure a convenient length along the bank of a stream, and time the journey, along this length, of bottles started at different points across the stream. Take the mean of the velocities of the various bottles as the velocity of the river over this stretch.

The action of running water.—Rain water which has fallen through unpolluted country air reaches the ground in a condition of almost entire purity. In its fall it has taken up more or less of the gases of the atmosphere, but it is as yet free from solid matter. But the moment it comes in contact with the earth it begins to exercise its **power of solution** on the solid particles of rock and soil. Certain constituents of these become dissolved and lost to view in the water as completely as a teaspoonful of table salt dissolves and is lost to view when stirred in a tumbler of water. In this state of solution such materials are carried to a stream and ultimately reach the sea. The solubility of the materials of rocks and soils is not dependent upon their hardness or softness, on their brittleness or on any other physical character, but is decided by their chemical composition only.

But the water carries with it not merely dissolved matter, but also (1) **suspended particles** which settle whenever the water comes to rest, and (2) masses of varying sizes and shapes which are pushed or rolled along the bed of the stream.

The extent to which solid bodies are transported in this manner depends upon many circumstances. Of these, one of the most significant is the lifting force which water—even when at rest—exerts upon all solid bodies immersed in it. The force is in each case equal to the weight of the water which the solid displaces. With an immersed body measuring one cubic inch, for example, the force is equal to the weight of one cubic inch of water. This upward force, acting alone, can, of course, actually raise from the bottom only those particles which are bulk for bulk lighter than water, whereas most rock fragments are heavier than water.

But in flowing water additional forces are brought into action. There is, first of all, the onward current of the stream, the power of which to transport the bodies in its bed varies *as the sixth power of its velocity*. "If a stream flowing with a given velocity is able to move stones weighing one pound, by doubling the velocity boulders weighing sixty-four pounds can be carried; and if the velocity were increased ten times, rocks weighing one million pounds could be moved." *

Secondly, the friction of the water against the sides and the bed of the stream causes *eddies* which result in various **upward currents.** These secondary currents vary in force according to many circumstances, but they are nearly always stronger in swiftly flowing than in slower streams, and their actual power of raising particles of sand, gravel and the like from the bottom depends largely upon the speed of the main current.

" In any channel, . . . the velocity of forward flow is greatest near the centre and least near the sides and bottom, and if it were possible to obtain a state of affairs in which the motion might take place in stream lines parallel to the axis of the stream, we should have, with steady flow along a straight reach of the channel, the *velocity greatest on the surface and at the centre* of the stream, and the water surface level from side to side. In practice this is modified by the eddy formation which always takes place at the sides of a stream." The result is that, " except in a broad, rapid and shallow stream, the **line of maximum velocity** is at some depth below the surface. . . . On a calm day it usually ranges from about one-tenth to four-tenths the depth of the stream."†

Now, the **rate of flow** of a stream of water—which affects its transporting power so greatly—is in its turn dependent, other things being equal, upon the slope of its bed. It follows that in most cases a stream contains the greatest amount of suspended matter where its bed is steepest ; while it deposits an increasingly greater amount of sediment as its bed becomes flatter and its flow less rapid.

Again, the rapidity even of a stream flowing over a bed of uniform inclination must obviously vary with variations in its width ; for we may assume that, under ordinary conditions, the same quantity of water is passing all points in the same interval of time ; and when this is so the speed through a narrow gorge must be greater than along a wider channel.

Where, either from the widening of its channel or from the more level character of the ground over which it is flowing, the speed of a stream becomes checked. the solid matter in suspension is deposited

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* Russell's " River Development " (Murray).

† *Vide* A. H. Gibson's article " On the Depression of the Filament of Maximum Velocity in a Stream flowing through an Open Channel " (*Nature*, April 1, 1909).

—the coarser and heavier materials first and the finer particles later. A river passing through a lake may be, from the former of these causes, almost entirely freed from suspended matter. This action occurs on a great scale in the case of the river which enters and leaves the Great Lakes of North America. The Niagara river from Lake Erie is practically free of suspended matter as it drops over the famous falls. The same process is operative in the case of the Victoria Nyanza. The Kagera which flows into it is turbid, and the Victoria Nile which leaves it at the Ripon falls is clear. The beautiful clearness of the water of the River Rhone at Geneva, so often cited, is an excellent example. There are less well-known cases in most countries—such as Great Britain and the Dominions—but India has practically no good example of this type. The Jhelum river, after passing Srinagar, flows into Wular lake, where it deposits much of the silt it carries during floods; nevertheless this river is not free of fine suspended matter when it flows out of Wular lake on its journey out of the Kashmir Himalaya on its way to the Punjab plains.

FIG. 103.—The Narbada river falls above the "Marble Rocks" near Jabalpur. (Photo by Hands.)

18. THE WORK OF A RIVER

1. Experiment to illustrate the origin of a river. (*Outdoor work.*)—Build up a mound of wet earth or clay, say a yard in diameter and a foot in height, and shower water upon it from a large watering-can. Observe (*a*) the various directions in which water runs from the highest parts (watershed) of the mound; (*b*) the union of small streams to form larger ones; (*c*) the occasional deflection of a stream by an obstacle in its path; (*d*) the gradual formation of valleys by streams and their tributaries.

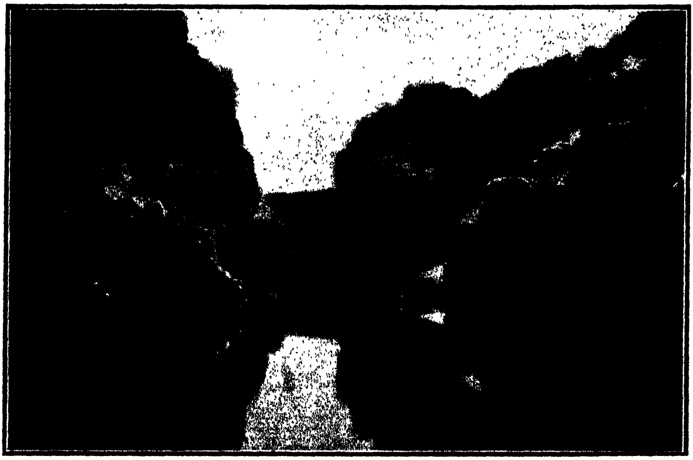

FIG. 104.—The Narbada river in the gorge of the "Marble Rocks" near Jabalpur. (Photo. by Hands.)

2. The formation of springs. (*Outdoor work.*)—Build up a mound with two or three alternating layers of sand and clay, and shower water upon it from a watering-can. Note carefully how the points of origin of springs are related to the character of the material above and below them. How do sand and clay differ in the ease with which water percolates through them?

3. The formation of a delta. (*Outdoor work.*)—Either immediately after a shower on any "waste ground" conveniently near, or by means of an artificial mound and a watering-can, as in Expts. 1 and 2 above, study the deposition of suspended matter by a stream on reaching flat ground. Look for examples of such a stream being blocked by sediment it has itself deposited, and study the manner in which it may have formed fresh channels through such sediment.

4. Field study of rivers. (*Outdoor work.*)—(*a*) Examine the Survey of India map of your district to find approximately where a convenient river has its source. Make an excursion to the source and make the following observations. Is the source at the top of a hill or at some distance down the slope? Does it consist of a spring? Can you suggest why a spring should be found in this position? How is the spring supplied with water? Follow the stream in the direction of its flow. Of what kind of rock is the bank of the stream? Is the channel of uniform width? If not, can you find any relation between its width and the hardness of the material forming the banks? What observations would lead you to suppose that the river has excavated its own channel? Collect a glass of water at intervals and observe whether it contains much suspended matter. Would a river of clear water or one carrying much suspended matter be more likely to deepen its channel? Would you expect a river, in general, to become deeper in a steep valley or on a fairly flat plain? For what length does the river seem to be engaged actively in excavating its valley? Find out from the Survey of India map (Fig. 29 of the Ravi valley at Chamba) what is the average slope

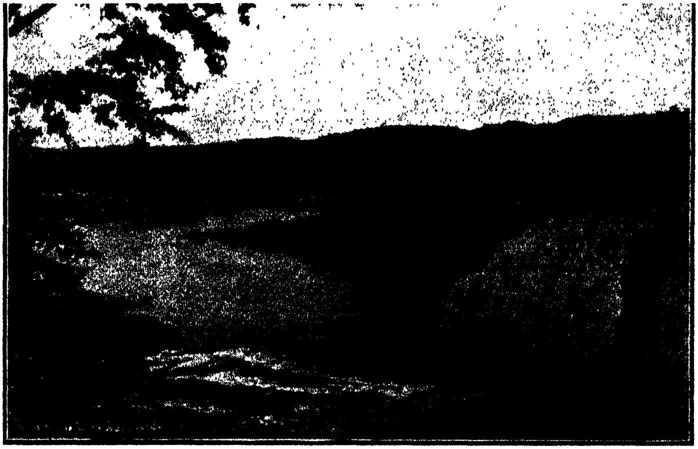

FIG. 105.—The Narbada river rapids below the " Marble Rocks " near Jabalpur. (Photo by Hands.)

(expressed in feet per mile) of the Chhararu nala from its source to its confluence with the Ravi near Bharian. Does it wind about much in this part of its course?

(*b*) Where does the river in your district begin to take on a winding course? Follow it round a bend and observe, by floating bits of paper or wood, or by the method of Expt. 5, p. 168, whether it flows more rapidly under the concave or the convex bank. Which, if either, of these banks shows signs of being undercut by the water? Which, if either, bank seems to be formed to any extent of material deposited by the river?

FIG. 106.—The Narbada river in the alluvial plains of the Jabalpur district, below the famous " Marble Rocks ". (Photo by Hands.)

Will the river, by long continuance of such action, tend to alter its course? Do you see any sign that a " short cut " may eventually be formed between one reach and another? On the Survey of India map look for other such loops or " meanders " in rivers, and in each case estimate approximately the slope of the land over which a river follows a winding course.

(*c*) If you have access to the place where a river discharges into a lake, or into the sea, look for signs that it has been compelled to form new channels through ground formed from its own deposits. Study the course of the river in Fig. 26 which begins near Dympep as the Um

Sohra, leaves the hills at Theriaghat as the Um Sohrryngkew and almost loses itself in the plains near Companyganj.

5. The profile of a river.—(*a*) Draw the profile of the River Ganges by the method used for road-book sections (p. 52) from the following particulars.* Height at source of the Bhagirathi river, at the glacial ice-cave of Gaimukh, 13,500 feet; about 140 miles from its source at the junction with the Alaknanda river at Devpryag 1700 feet; 180 miles from its source at Hardwar, where it finally emerges on to the plains, 980 feet; at Allahabad (Pryag), where it is joined by the Jumna 700 miles from its source, its height above sea level is 280 feet; at Patna, just below its junction with the Son and 1000 miles from its source, it is 170 feet; and at Goalundo, 1400 miles from its source, where it is joined by the Jamuna (new Brahmaputra), it is 20 feet above sea level and tidal. Its total length is 1550 miles to the sea, so that its fall is roughly 9 feet per mile for the whole distance. Use a vertical scale of ½ in. to 1000 ft. and a horizontal scale of ½ in. to 100 miles.

(*b*) To suitable horizontal and vertical scales, draw the profile of the river studied practically in Expt. 4 (*a*) above.

An instructive miniature.—No opportunity of studying at least the upper part of a river valley by personal observation should be lost. " It is ", says Lord Avebury,† " a beautiful and instructive miniature. The water forms a sort of small-meshed net of tiny runnels. We surprise the river at its very commencement: we can find streamlets and valleys in every stage; a quartz pebble may divert a tiny stream, as a mountain does a great river; we find springs and torrents, river-terraces and waterfalls, lakes and deltas, in the space of a few square yards, and changes pass under our eyes which on a larger scale require thousands of years.

" And as we watch some tiny rivulet, swelling gradually into a little brook, joined by others from time to time, growing to a larger and larger torrent, then to a stream, and finally to a great river, it is impossible to resist the conclusion gradually forced upon us, that, incredible as it must at first sight appear, even the greatest river valleys and plains, and the general configuration of the land, though their origin may be due to the initial form of the surface, are due mainly to the action of rain and rivers."

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* De Rance (*Proc. Geol. Assoc.*, vol. iv. 1875).

† " The Scenery of England ", p. 322 (Macmillan).

The origin of a river.—The rain * which falls on high lands at once begins to flow downhill. If the surface of the ground is **impervious,** the water runs along it, taking advantage of every slope to find a lower level. If the surface soil, on the contrary, is composed of sandy, gravelly or other **pervious** material, the water sinks through the ground until it comes to an impervious layer, which arrests its vertical progress, and it then flows along this layer until it reaches the surface as a **spring.**

Surface springs.—The formation of simple springs of this kind will be understood readily by reference to Fig. 107. This illustration shows a section across a valley. The beds (*b*) are made up of sand and gravel, those marked (*a*) are of clay. The rain which falls in this neighbourhood will flow partly over the surface, but the greater part will sink into the ground and will meet with little obstruction to its course until the bed of clay is reached, since sand and gravel are porous. Reaching the bed of clay, it will be unable to sink further, and consequently will collect at the line of junction. The result will be that where the sand has been worn through, exposing the clay (*a*) as shown in Fig. 107 between *ss*, the water, which has collected in the manner described, issues in the form of a spring. Because of the nearness of the underground water to the surface, springs of this kind will be immediately dependent upon the rainfall. In seasons of drought the spring will cease, while in rainy years there will be an abundant supply of water. The water which issues from surface springs is very liable to be contaminated with drainage and other impurities from the surface.

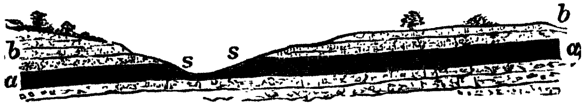

FIG. 107.—Surface springs: *a*, are impervious; *b*, porous beds.

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* The origin of rain is described in Chapter XIII.

Artesian wells are artificial springs, and as such have, of course, no share in the formation of rivers. They may, however, be conveniently referred to here. They become possible when a porous stratum of rock occurs interbedded between impervious layers of rock, and all these strata sag to the shape of a basin or a trough. If the porous bed is thick and is exposed along the margin of the basin at a higher level than the middle of the basin surface, then the conditions of finding water under pressure are good. If a well or boring is made to the porous bed from the middle of the basin, the water underground will rise up the bore tube and overflow at the surface, Fig. 108. Such a well is known as an artesian well, after the French province of Artois where these wells were first understood.

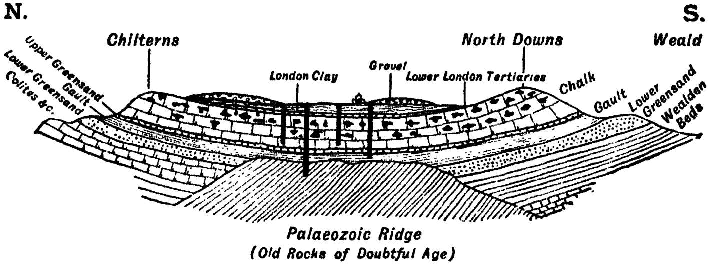

FIG. 108.—Section from the Chiltern Hills to the North Downs, to show the London Basin and the principle of an Artesian Well. The basin-like form is much exaggerated. (Drawn by Mr. W. C. Simmons.)

In India no typical cases of artesian wells for fresh water are worth quoting. In the Quetta valley such wells did occur, but the underground pressure has become so reduced that the water does not now flow out at the top of the well. There are many places both in India and other countries where underground water in a porous stratum rises to a considerable height in a bore tube but does not flow out; such cases are best referred to as sub-artesian.

Fig. 108 gives a rough idea of the way the rocks lie round and under London. The basin-like character of the rocks is very much exaggerated so as to exhibit the arrangement on which the possibility of such a well depends. Near the surface are beds of clay, known as the *London Clay*; then follow beds known as the *Lower London Tertiaries*; they are made up largely of porous sands, but thin layers of clay occur at different levels. These clayey strata being impervious, serve to retain the water which sinks down into the sands, and water gets stored up at the junction. If a boring is made through the London Clay down into these sands and gravels, the water which has collected there seeks its own level, and being much higher near the outcrops of the lower beds, the water flows out at the boring and rises to this height, or as high as the water has collected in the sands.

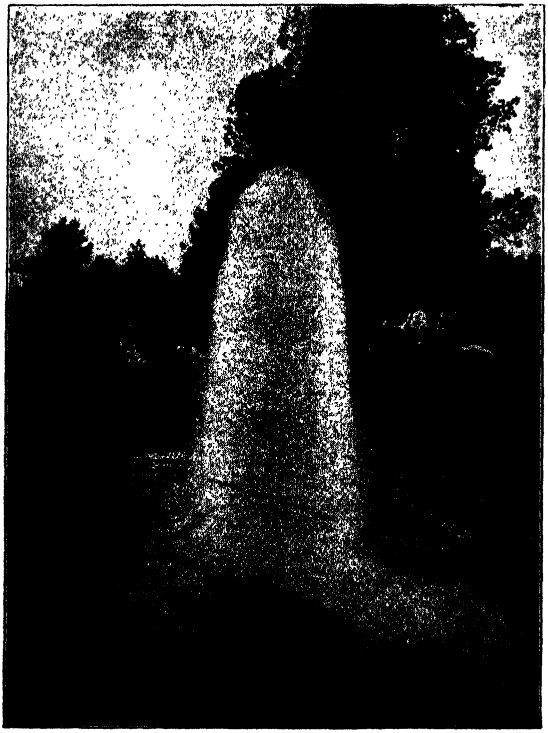

FIG. 109.—Artesian Well in Australia.

In Fig. 108 borings are shown penetrating the lower beds; some of these beds are of chalk, which is remarkable amongst other things for the large number of crevices which it contains, and in these the water collects in a manner which cannot, however, be predicted, since the cracks follow no definite order ; the clayey *Gault* below the chalk prevents the water from escaping below, but if one of the numerous fissures be struck by the boring, the supply of water from the outlet at the surface is much augmented.

Rivers.—Part only of the rainfall of a district sinks into the ground and gives rise to springs, another larger portion flows over the surface, collecting into runnels, which continually unite, until at last a stream is formed. It is by the union of streams of this kind, together with those which have their origin in springs, that rivers are formed. Rivers can thus be regarded as the surplus rainfall running off to rejoin the ocean.

In addition to the water, however, as has been seen, rivers contain a large amount of mineral substances dissolved, which being added continually to the ocean, maintain the saltness of sea water. Not only are dissolved materials thus removed from the land by rivers, but also a large amount of suspended matter, which is hurried forward by the force of the moving water ; concerning this, more will be said later.

Terms used in describing rivers.—It will be well first to explain the terms which are in common use in describing a river. The commencement of the river is called its **source** ; this may, as in the case of the Ganges (Bhagirathi) be from an ice cave at the so-called " snout " of a glacier below the snow-line, where the temperature is high enough to cause a constant melting of the snow or ice ; or it may arise from a spring, as in the case of the Narbada on the highland of Amarkantak ; or it may originate in a marsh, or lake, as was till recently the case of the Sutlej, the source of which was in the westward overflow from the Manasarowar lakes. In almost all cases, whether it be the Ganges, the Sutlej, the Nile, or the Thames, it is difficult to locate the exact spot where the river begins. Indeed, speaking generally, it may be said that less is known of the source than of any other part of the rivers.

The river empties itself into the ocean at its **mouth**, and proceeds from its source to its mouth along the direction of its **course**. Standing at any spot along the course of a river and looking in the direction of the mouth, that is along the direction in which the water is flowing, we call the bank on the right the **right bank**, the other the **left bank**.

The water of a river represents the drainage of a certain tract of country, and a name is given to this area ; it is known as the **river basin.*** The highlands dividing one river basin from another constitute a **watershed** (Fig. 191).

The upper course of a river.—The course of a river may be divided into three portions, viz. the *upper* or mountain portion, *middle* or plains course, and *lower* or deltaic part. The upper is that part which flows down and between steep mountain slopes, and remains in this part of its course within the mountains ; it is characterised by its **waterfalls,** where the water drops a considerable height from one ledge to the next ; by its **cascades,** which are simply successions of waterfalls ; and by its **rapids,** where it rushes through deep and often impassable **gorges** and **defiles,** which hold its waters within narrow confines.

It is in its upper course that a river accomplishes the greater part of its work of erosion or wearing away the rocks over which it passes. The action is chiefly due to the friction of the coarser fragments which the river moves along its bed, and the erosion is naturally greatest where the bed is steepest and the flow most rapid. The result is that the deepening of the bed near the source continually **cuts back the source** itself. The consequences of this action are ultimately very far-reaching. The gradual cutting back of the source of the river obviously increases the distance from source to mouth, and therefore lessens the average slope of the river bed. It is plain, also, that some amount of shifting of the watershed is involved where a river on one side of the divide is cutting back at a greater rate than a stream opposite to it on the other side. In this process, the more active of two such streams often cuts into the head waters of the weaker river, and—if it provides these head waters with a greater fall—annexes them. This is known as **river capture** ; some apparent instances of it in our own country are mentioned on p. 310.

The result of friction on the excavating tools themselves is no less marked. As the stones and gravel move along, the persistent rubbing against the channel and one another which they undergo, causes them to get gradually smaller and smoother, eventually giving rise to the "water-worn" appearance which characterises the pebbles at the bottom of a stream or river. The suspended material causes too great a degree of turbidity in the water for the more slowly moving layer on the bed of the river to be visible.

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* The drainage water is almost entirely run-off rainfall and so the area from which a given river, or a particular tributary, carries away this run-off rainfall is often spoken of as the *Catchment area.*

Where eddies are produced in the course of a river the loose fragments are whirled round and round and tend to produce hollows, called **pot-holes,** in the river's bed.

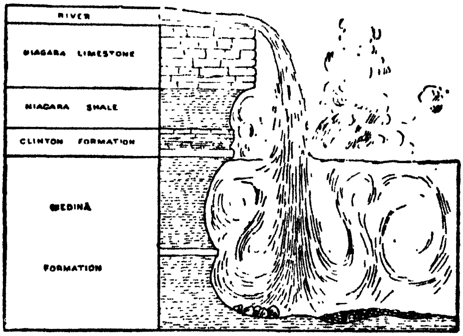


FIG. 110.—Section of the rock at Horseshoe Falls, Niagara. Scale: 1 inch = 307 feet.

The most important factor determining the extent to which this wearing away goes on is, however, the nature of the rocks over which the river flows. Hard rocks will be excavated to a much smaller extent than soft ones. One of the best examples of this is afforded by the falls of Niagara, situated between Lake Erie and Lake Ontario.

The river flows from the former lake to the latter, and passes over a series of beds arranged as shown in Fig. 110, which shows a section of the rocks at the Horseshoe Falls. The bed of the river is formed by the hard Niagara limestone which overlies the softer shales and sandstone. The water as it rushes over the fall dashes against the underlying softer rocks and wears them away at a great rate, thus undermining the limestone, which eventually, by its own weight, falls into the rapids below and is washed away.

That this kind of action has being going on for some time, and at a rapid rate, is shown clearly from the following considerations. At Queenstown, seven miles distant from the Horseshoe Falls, the limestone forms an inland cliff or **escarpment**, and a deep trench extends from this place back to the falls. An examination of the nature of the gorge makes it evident that the river has eroded a channel seven miles in length. Careful observations give as the yearly amount of erosion at these particular falls 2 feet 2 inches. From 1848 to 1890, some 275,400 square feet of rock had been washed away.

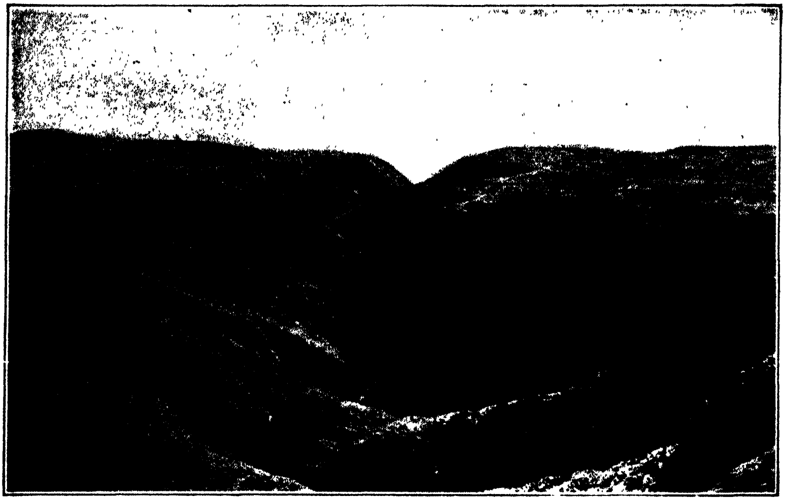


FIG. 111.—V-shaped Cañon cut in an upland recently elevated from the sea, San Clemente Island, California (after W. S. Tangier-Smith).

Perhaps the most magnificent instance of river erosion is afforded by the **cañons** of Colorado—particularly the Grand Cañon of the Colorado river—a region which is almost rainless. These cañons are gorges with, in many cases, nearly vertical sides cut out of horizontal beds of soft rock by the river found at the bottom of the ravine. Very impressive cañons occur at the **headwaters** of the Kistna river, north-east of Mahabaleshwar, at the edge of the Western Ghats; but here the rocks involved are almost horizontal beds of basaltic lava, the Deccan Traps, which have been carved into steep-sided valleys over 2000 feet deep. The deep valleys which almost encircle the plateau of Cherrapunji, Fig. 26, are steep-sided enough, Fig. 25, to be called cañons.

A striking example of the erosive action of the upper course of a river is seen below Balula, in Afghanistan, where the Bamian river, a tributary of the Oxus or Amu Daryia, has cut its way through the Hindu Kush mountains, forming a deep gorge, the Shikari tangi, the sides of which, in parts, for more than a mile, are almost vertical.

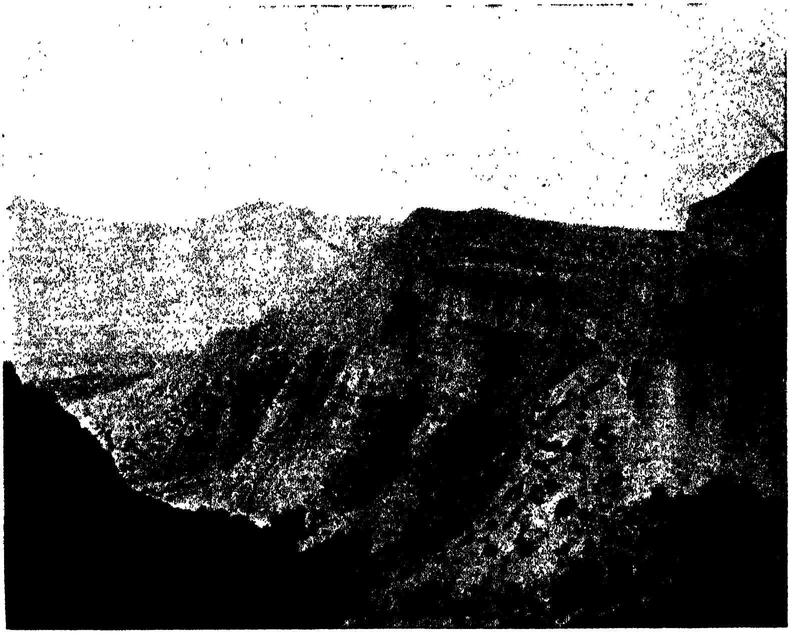


FIG. 112.—The Jutana Cañon, Punjab Salt Range. This deep gorge exposes the oldest fossiliferous strata of India. (With the permission of the Director, Geological Survey of India. Photo by C. S. Fox.)

It ought to be remembered that even in the upper course of a river the valley is not only being *deepened* in this manner, but is also being *widened* by rain, wind, and other agents which break up the valley sides, cause landslips or mud slides, and favour the incessant fall of loose earth and stones to the bottom. The normal result is that the valley becomes either wide and flat-bottomed, or, with more erosion, V-shaped in cross-section (Figs. 111 and 113). It is therefore in districts where the erosion of the bed of the stream far outruns the widening process, that gorges, cañons, and steep valleys generally are produced. Conditions favourable to their development are, obviously, scarcity of rainfall but very heavy precipitation when it does rain ; swiftly flowing streams, subject to frequent floods or spates ; and rocks which, from their relative lack of hardness combined with horizontality, or their hardness alone, do not readily collapse under severe erosion.

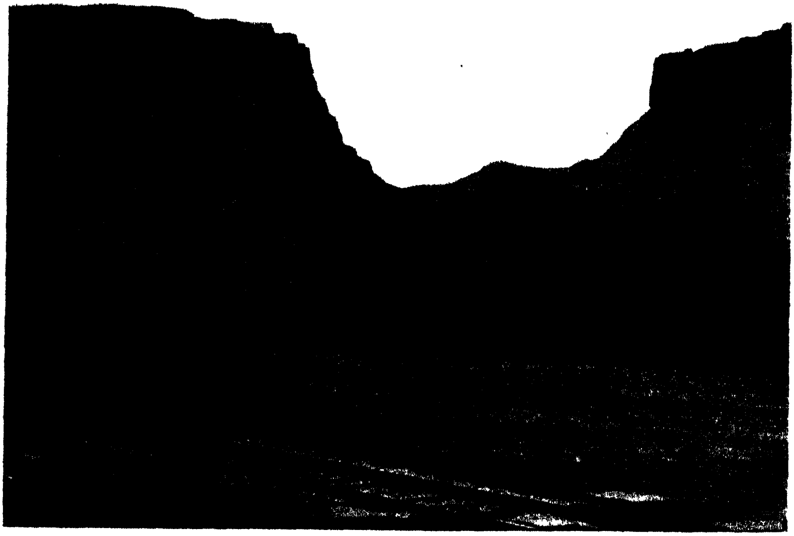


FIG. 113.—The Chapper Rift, a fine V-sectioned gorge on the Harnai route to Quetta, Baluchistan. The Lower Tertiary strata which have been cut through, arch over into the valley beyond. (With the permission of the Director, Geological Survey of India. Photo by C. S. Fox.)

In the case of every river, however, the process of excavation comes ultimately to an end, for plainly a river cannot deepen its valley below the level of its own mouth, nor a tributary excavate its bed lower than that of the main stream, since to do either would be to reverse the direction of flow. Thus each river at last attains what is called its **base level of erosion**, at which excavation of its bed ceases. In the course of ages the valley sides themselves must also be levelled, and the final result is a **peneplain** (*i.e.* almost a plain).

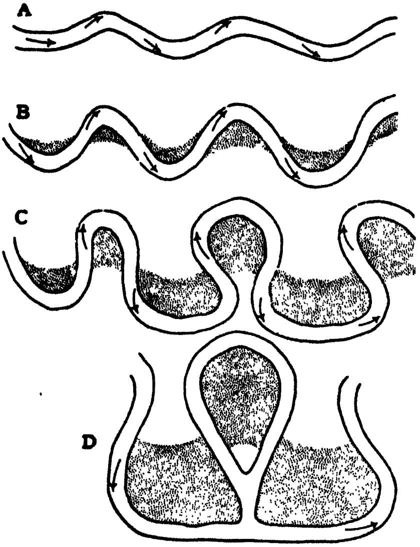
The middle or plains course of a river.—The middle course of a river differs chiefly from the higher portions in the fact that here its valley is being generally widened rather than deepened. The decrease in the steepness of its channel is marked by a corresponding diminution in its velocity, and it is chiefly in this part of its journey to the sea that it is joined by other, often equally important, streams called **tributaries**. The place where two such rivers join one another is called their **confluence**.

The character of the river's course will depend upon the rate at which the steepness diminishes. If it flows over a country where the altitude decreases very gradually, it will wind about, seeking the place of greatest slope, and will have a long, meandering course. On the other hand, should there be a regular fall towards the sea its path will be straighter, though even then its direction will be influenced by the hardness or otherwise of the rocks over which it flows.

It is in its middle course that a river begins to deposit appreciable amounts of sediments as a result of diminished speed of flow. Such deposits receive the general name of **alluvium**. At the foot of a steep hill—especially in a region subject to very scanty or infrequent rains—a fan-shaped or conical deposit is often formed in this manner; and the union of such *alluvial fans* produced by neighbouring rivers has given rise in various parts of the world to *alluvial plains*. The upper basin of the Indus may be quoted as an example. Such plains are often called *piedmont alluvial plains* to distinguish them from the level expanses produced by the meandering of rivers in the next part of their course (Fig. 117).

Where it encounters obstacles which, over steeper ground, would have been insufficient to change its direction, the river may now be compelled to turn aside, so that its course consists of a succession of pronounced curves or **meanders**. Thus, as a result of its diminished energy, the river in this second stage of its journey tends rather to widen than to deepen its valley as it turns from side to side, and to produce equality of surface in its neighbourhood.

It will be interesting to consider the results which may follow the deviation of a river out of its direct course, caused by some obstruction in its path. When it has turned aside, it tends to continue in its new direction, in accordance with Newton's First Law of Motion (p. 98); on the other hand, the force of gravitation is pulling it back to its former line of flow, and presently, as a compromise between these forces, added to the resistance offered by the " outside " bank, the river describes a loop, such as is shown in Fig. 114. It is plain that the force of gravity will have less effect over a slight slope than over a steep one, so that rivers have a tendency to produce the greatest curves over the most level country. Many other circumstances must, however, be taken into account in any attempt to explain the phenomena completely.



A. B. C. *Stages in the development of Meanders. Alluvium dotted.* D, *First stage of Ox-bow Lake or Mortlake.*

FIG. 114.—Development of the middle course of a river.

Further, it may be observed that the current strikes with more directness and force on the outside or concave bank of the curve, and therefore undermines this bank and gradually cuts it back. This action is the more pronounced where the curves are sharp, and an examination of Fig. 114 shows that the natural result is for the two ends of the loop to approach each other, as their concave banks are excavated, until at length (Fig. 114, *D*) they join, and the river once more flows in a fairly direct line. The loop is then left as a pool of standing water, surrounding an island. (One is shown in the aerial photograph of the course of a river in the Darbhanga district of Bengal in Fig. 116.) It is presently cut off by alluvial deposits from the main stream, forming an " Ox-bow lake " or " mortlake ".

On the other hand, whilst this is in progress, the convex banks are receiving material scoured from the opposite banks, and also deposits of material (alluvium) which the river has carried in suspension from the hills, so that these banks become gently shelving (Fig. 115) as they extend more and more inward. The net result of all these processes is, as was stated above, to widen and level the river valley, converting it into an **alluvial plain** (Fig. 116).

After heavy rains, a river often overflows in the middle part of its course. The sudden checking of the speed of the overflowed water causes the deposition of its suspended matter. This gradually builds up embankments above the general level of the plain.

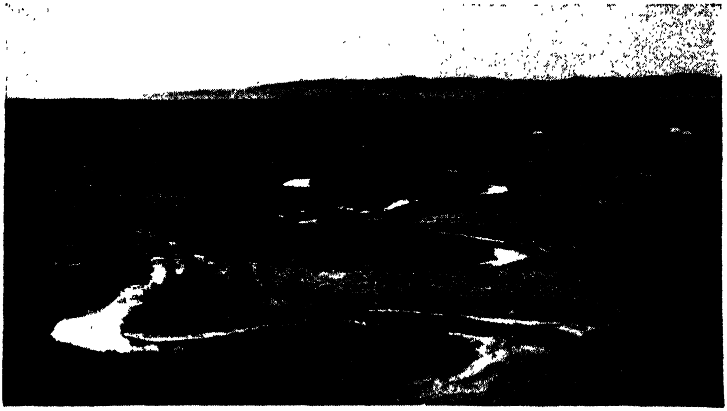


FIG. 115.—River meandering in an alluvial flat, Laramie Basin, Wyoming. (From *Bull. U.S. Geol. Surv.*, No. 364, 1909.)

River terraces.—It sometimes happens that a valley bottom is raised by earth movements. The general gradient of the river is thereby increased, and active erosion of the bed recommences even in the middle course, so that the stream eventually flows at a deeper level than before. The former banks of the stream are then sometimes to be seen as river terraces, forming more or less horizontal shelves along the sides of the valley (Figs. 111, 112, and 113).

The lower or deltaic course of a river.—As the river continues its course towards the sea or lake into which it discharges itself, its fall becomes slighter and slighter, and its rate of flow slows down. The materials carried in suspension are deposited, the gravel and sand first, the silt or finer materials later, until only the finest mud remains in suspension. Even this settles gradually to the bottom when at length the flow is checked entirely. The deposit accumulates in a low, fan-shaped slope (Fig. 117), in which the river splits or distributes itself in channels which diverge. This portion marks the beginning of the deltaic course—a name taken from that given to the Nile outlet to the sea, which in its shape resembles the Greek letter Δ, delta. This slope is of varying steepness, according to the suddenness with which the current is checked; and unless it is removed by tidal action it in time blocks the outlet of the river, so that a new channel or channels must be formed. In the case of the

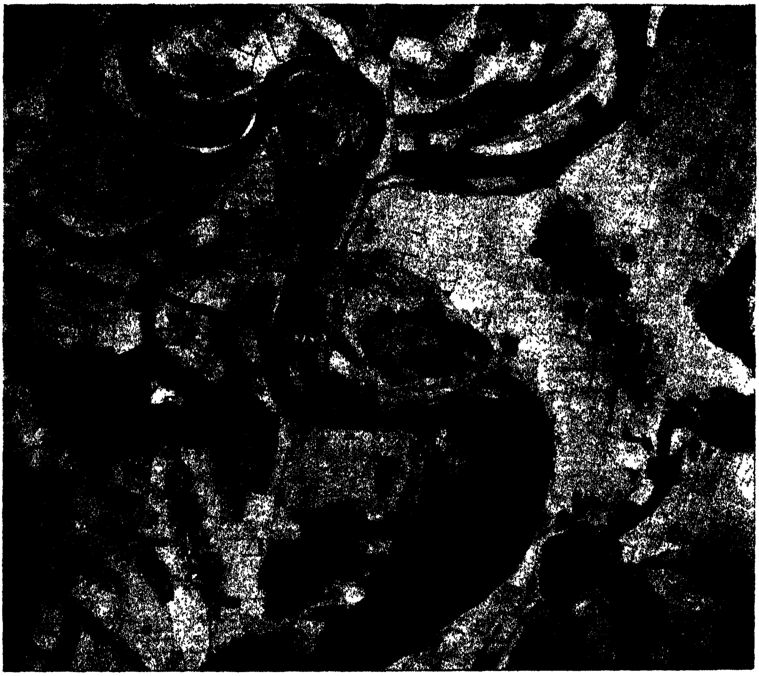


Fig. 116.—An aerial photograph of river meanders in the alluvial plains of Darbhanga, northern Bengal. The picture shows evidences of at least two earlier changes in the river's course. (With the kind permission of the Indian Aerial Survey and Transport Co., Ltd., Dum Dum.)

Ganges river the deltaic portion begins a little below Rajmahal and close to the ancient town of Gaur, now in ruins, where the first distributary, the Bhagirathi, which lower down becomes the Hooghly river of Calcutta, leaves the main stream. Such new channels naturally tend to form secondary deltas of their own, and it is in this manner that the Ganges delta in Bengal has been formed. In the case of the Persian Gulf there is no doubt at all regarding the silting up which has been effected by the combined Euphrates and Tigris rivers below Basra. This town which was originally on the coast is now separated from the sea by a considerable tract of land—more than 50 miles—which has been formed in this manner.

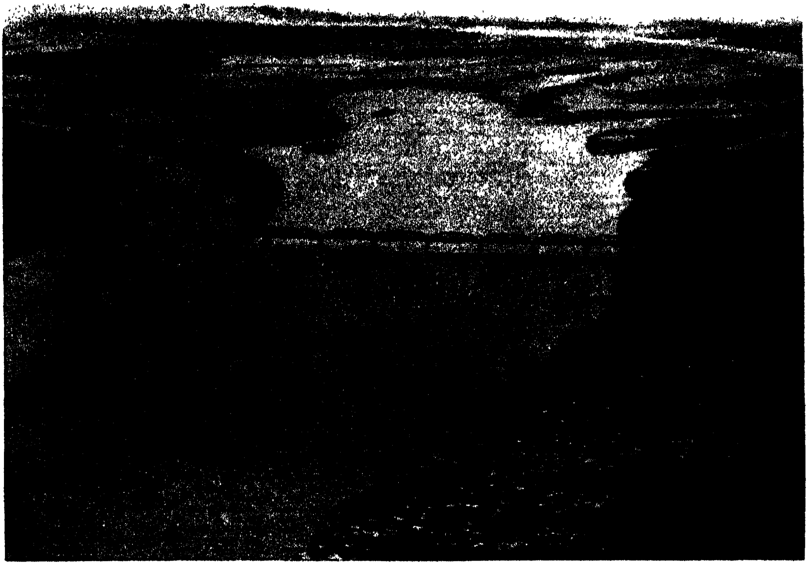


FIG. 117.—The debouch of the Indus from the hills at Kalabagh. As seen in this view the river has spilled and formed a deltaic fan on emerging into the Mianwali plains. (With the kind permission of the Director, Geological Survey of India. Photo by E. R. Gee.)

In order that a delta of this order may be formed, several conditions must hold good:

(1) The coast at the mouth of the river must be sheltered;

(2) There must be an absence of currents and tidal movements in the waters of the sea into which the river empties itself; and

(3) The velocity with which the river flows into the sea must not be sufficiently great to carry the suspended material far away from the coast, *i.e.* the materials must be deposited in the sea near the river mouth more abundantly than they are carried away by the movements they meet with in the sea.

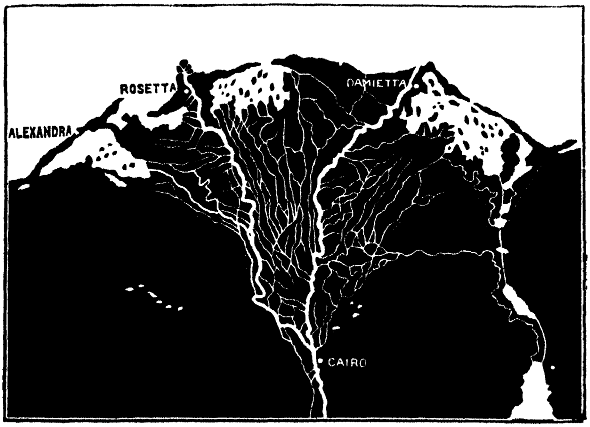


Fig. 118.—The delta of the River Nile.

Fig. 118 shows the delta which has been thrown down by the River Nile. The area enclosed by lines joining Cairo, Damietta, and Rosetta is in the shape of a triangle. From an examination of the nature of the deposits forming the country between Cairo and Damietta, it is clear that at one time the Nile entered the sea at the former place, and that the alluvium which extends from it to the Mediterranean, a distance of 100 miles, has been thrown down gradually by the river. The distance from Rosetta to Damietta is 90 miles, but from the extreme mouths of the Nile, as shown by the dotted line in Fig. 118, the distance is more nearly 200 miles.

Borings have been made in the Nile delta, and have revealed the fact that the alluvium reaches to a depth of 120 feet : this represents more than 1,500,000 millions of tons of silt deposited below Cairo by the Nile and forming land at the present time. Some idea of the immense amount of erosion in the upper parts of the river's course which this represents is thus formed and the necessity for some compensating influence to prevent the whole of the land being worn down to the sea level is appreciated ; to this attention will be directed later.

In the case of certain other of the large rivers of the globe, deltas of still greater magnitude have been deposited, and amongst these the Mississippi and the Ganges-Brahmaputra may be mentioned. The area of the Ganges-Brahmaputra delta south of a line joining Rajmahal with the south-west corner of the Garo Hills is no less than 72,000 square miles, and a boring to a depth of 480 feet at Fort William, Calcutta, did not reach solid rock. The amount of silt deposited in this tract is over 30 times larger than that which underlies the visible portion of the Nile delta.

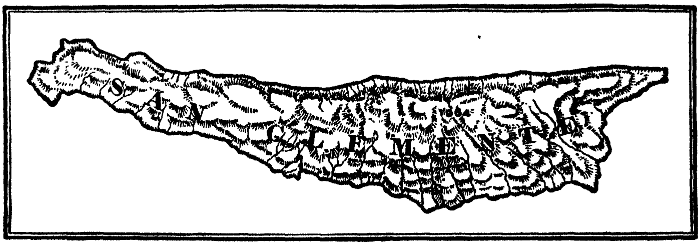


FIG. 119.—Map of San Clemente Island, California, showing the characteristic topography of recent uplift (after U.S. Coast and Geodetic Survey).

River profile.—A section drawn, as in Expt. 5, p. 175, to show the changing gradient along the whole course of a fully developed river reveals a number of instructive differences between the various portions. In the mountain tract, where the river is excavating its bed, such a river profile is steep, often interrupted by waterfalls, and *concave* to the sky. In the lower part of its course the profile is more gently curved, and is slightly *convex* to the sky, owing to the deposits of alluvium.

The normal cycle of erosion.—When any area, previously submerged, is raised above the surface of the sea, it is at once exposed to the attacks of rain, running water, and other agents of denudation. For a time their action produces increasing irregularity of the surface. At first the rivers are shallow; naturally take the shortest courses to the sea; are, in a general sense, parallel to each other, and have but few tributaries. Later, the direction of flow is more and more determined by the ease or difficulty with which rocks of different degrees of hardness or solubility are eroded. Waterfalls, gorges and escarpments are formed; watersheds become zigzag; and " river capture " gives rise to increasingly complicated tributary systems. As time goes on, more and more material is removed from the higher ground and spread out in alluvial flats or deltas; waterfalls and other irregularities in the beds of the streams are worn away, so that the " river profiles " become smoother and flatter; and finally the " peneplain " condition completes the cycle. These various stages in the modification of the land surface are often described as youthful, mature and old (Fig. 120). They are to be studied in the upper, middle and lower course respectively of a typical river.

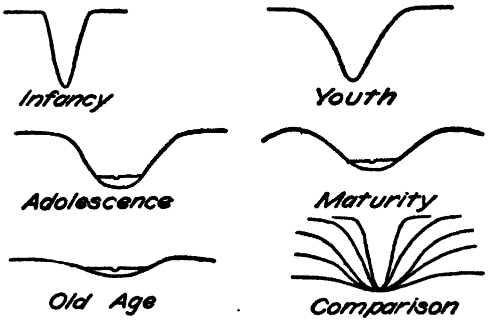


FIG. 120.—Comparison of the cross sections of river valleys for the different stages of the erosion cycle.

Such a normal cycle is of course liable to be interrupted by movements of the earth's crust, by changes in the sea-level, or by glacial action (p. 204), so that an area in an advanced stage of erosion sometimes acquires a new lease of " youth ", with a corresponding effect upon the topography (Figs. 121 and 122).

Tidal rivers.—In the case of those rivers which flow into a long narrow opening of the sea, as, for instance, the Hooghly below Diamond Harbour, the movements of the sea will influence the height of the river, to distances from its mouth varying in the case of different rivers. One of the most familiar of the movements of the sea is the **tides** (Chap. XI). The tides are great waves which travel round the earth as it rotates, and are caused by the differential attraction of the sun and moon upon the earth. These waves are noticeable at all places on the coast, causing the phenomena known as high and low water. In the case of the Hooghly the influence of the tides is felt as far up the river as the confluence of the Jalangi and the Bhagirathi, and tidal bores get up to Chinsurah, where the first European (Dutch) port was established in Bengal. Above the town of Nadia, from the railway bridge joining Hooghly with Naihati, the water flows steadily seawards throughout the day, while below this place, and above Chandernagore, during one part of the day the direction of flow is *up* the river, and during the other *down*. At Calcutta the tidal effects are strong and the resultant motion of the waters of the Hooghly estuary effectually prevents the formation of a separate delta at the river's mouth, though there is a continual but irregular deposition all down the channel, especially below Diamond Harbour and even out at sea, south of Sagar, at the so-called " Sandheads "—to the formation of shoals, or **sands,** such as the dreaded James and Mary sands just below the junction of the

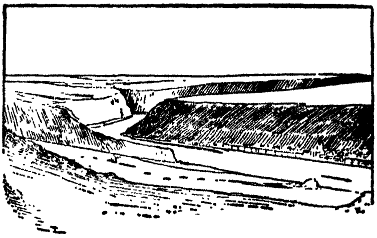


FIG. 121.—Gorge of the River Rhine near St. Goars, incised within an uplifted plain which forms the hill-tops.

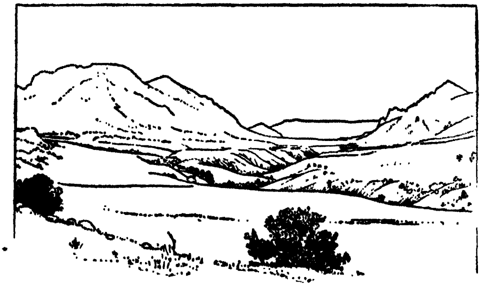


FIG. 122.—A rejuvenated river valley (after a photograph by Fairbanks).

Damodar river with the Hooghly. Often the retarding effect of the inflowing tide upon the outward movements of the river's water causes a deposit of the nature of a **bar.**

In some cases, such as the Hooghly, the Meghna and the Salween, where the channel is narrow, the combination of a rapidly rising tide with a swiftly moving river causes the inflowing water to be forced up to a considerable height, constituting a **bore** (Fig. 124).

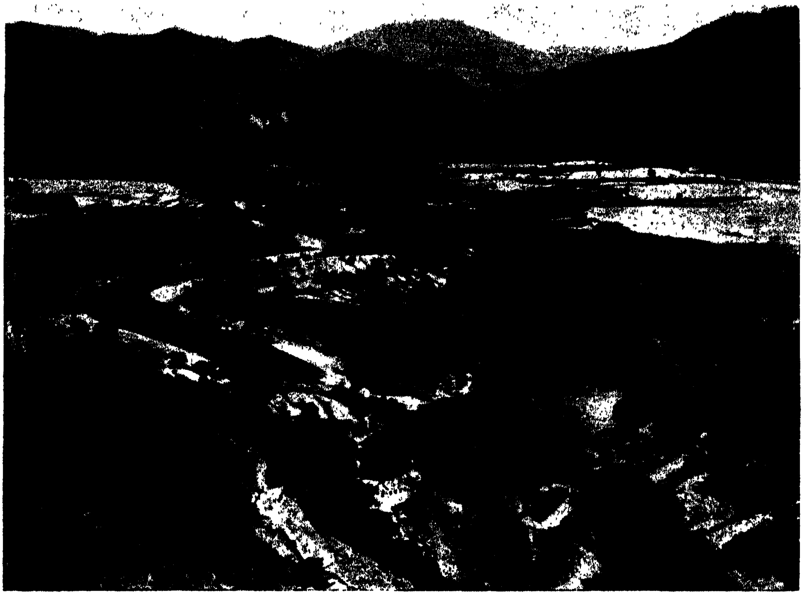


FIG. 123.—The Sutlej, looking downstream from Chaber, north of Simla. The view includes two alluvial terraces at different levels. The one on the right is the older. (With the permission of the Director, Geological Survey of India. Photo by W. D. West.)

Bores.—The conditions necessary for the formation of a bore appear to be three in number :

(1) A swiftly flowing river ;

(2) An extensive bar of sand, dry at low water, except in certain narrow channels kept open by the outgoing stream ;

(3) The estuary into which the river discharges must be funnel-shaped, with its wide mouth open to receive the tidal wave from the ocean. In the Hooghly all these conditions are more or less present, and hence a bore occurs.

Bore of the Hooghly.—The bore of the Hooghly is remarkable for its rapid rise and swift progress. It is occasioned by heavy rains up country increasing the volume of water in the river, and thereby imparting a greater velocity and duration than usual to the ebb tide, to overcome which an excessive effort is made by the first flood. Its strength is much greater in the south-west monsoon than during the north-east monsoon. In March, when the equinoctial tides prevail, it is frequently high and dangerous. From May to October its presence is not uncommon at the height of the spring tides, but its strongest effects are felt between July and September in the two days before and the two days after the full moon. At Calcutta, where the bore (Fig. 124) sometimes rises at once to the high water mark of neap tides, great crowds of people are generally

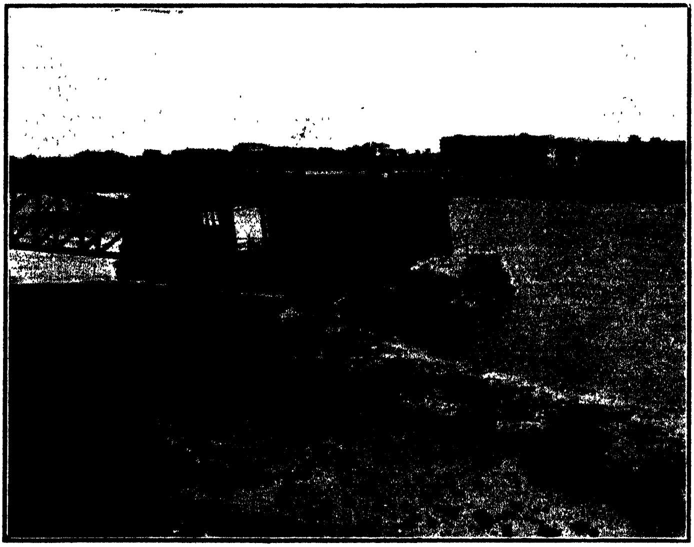


FIG. 124.—A " Bore " on the Hooghly. View taken from the Shalimar bank looking across to Calcutta. (With the kind permission of *The Statesman*, Calcutta.)

on the look out for it when it is expected. Its rate of progress up the river is about 20 miles an hour, and in many places it appears as a strong wave more than 4 feet high.

19. GLACIERS

1. Ice lighter than water.—Put a block of ice, if possible rectangular in shape, into water, and estimate what proportion of the block is submerged. From your measurements, calculate the size of the ice produced when one cubic foot of water freezes.

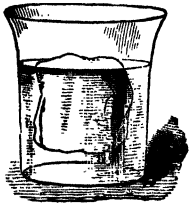


FIG. 125.—Ice is lighter than water.

2. Regelation.—(*a*) Press two blocks of ice together. What is the result?

(*b*) Support a block of ice between two stools, and suspend from it a heavy weight attached to a wire. Notice, as the wire gradually cuts its way through the block, whether the pieces produced remain separate or become united again above the wire.

(*c*) (*Outdoor work.*)—In frosty weather fix a straight icicle by one end in a horizontal position, leaving the rest of its length unsupported. Describe any changes in the shape of the icicle. Treat a stick of sealing wax in the same manner, and compare the results.

(*d*) Fill an empty stone ginger-beer bottle with snow. Put a stick through the bottle neck and hammer it in, so as to force the snow into as little space as possible. Take out the stick, put in more snow, and again hammer. Repeat until you have put in all the snow the bottle will hold, even under pressure. Now break the bottle and examine its contents. By what means can snow be turned into solid ice?

3. Signs of former glacial action. (*Outdoor work.*)—Visit the nearest museum, particularly the Indian Museum at Calcutta, and study any glacier-scratched stones exhibited in it. Note that the localities from which the stones were obtained are nearly all either in the Punjab Salt Range or the Simla hills, and that the specimens belong to an old geological epoch. Glaciers, however, occur in the Kumaon and Kashmir Himalayas, and scratched stones are found in the glacial debris in the valleys in which these glaciers occur. Should you visit the Gangotri glacier or Badrinath you will have opportunities for the study of glacial action described on pp. 202 and 205 and be able to obtain photographs of any found. Make notes of any erratic blocks in your Himalayan tour,

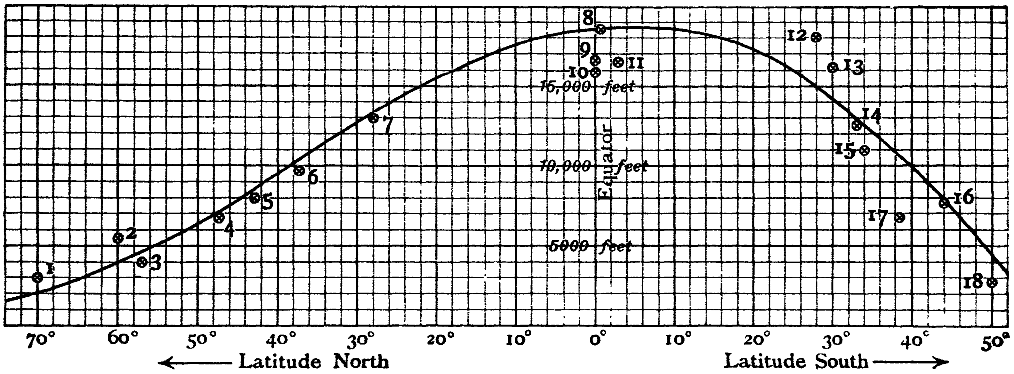


FIG. 126.—Diagram showing height of snow-line in various latitudes. 1, Lapland; 2, Alaska; 3, Ben Nevis; 4, Tauern (E. Alps); 5, Pic du Midi (Pyrenees); 6, Mt. Etna; 7, Himalayas, south side; 8, Bolivian Andes, west side; 9, Andes at Quito; 10, Bolivian Andes, east side; 11, Kilimanjaro; 12, 13, 14, 15, 17, 18, Andes (Chile); 16, Alps (New Zealand). In the Assam or Eastern Himalaya the snow-line is probably not lower than 18,000 feet in latitude 28° N.; in Sikkim about 16,000 feet in latitude 28° N.; in Garhwal about 15,000 feet in latitude 30° N.; and in Kashmir between 13,000 and 11,000 feet in latitudes 35° N. to 36° N.

with particulars of the kind of rock of which they are composed, the place from which they were probably brought by glaciers, and any other details you may be able to obtain from local geologists. Study the geological map of your district and see whether glacial drift is marked on it; if so, try to find specimens of the drift and make notes of its nature.

Snow-line.—Above a certain height on a lofty mountain the snow never melts. The line above which snow always exists is called the **snow-line.** As might be expected, it is highest in equatorial regions, falling at last to the sea level as the poles are approached. The height of the snow-line does not, however, vary regularly with the latitude, as is clearly shown in Fig. 126. Temperature is the factor of greatest importance, but its influence is modified considerably by the *amount of snowfall,* as well as by other circumstances.* In India permanent snow lies only upon the Himalaya and related high mountain ranges. The diagram shows, incidentally, that in the southern hemisphere the snow-line reaches sea level in lower latitudes than in the northern hemisphere. " In India it is difficult to determine the snow-line accurately because the region of permanent snow passes gradually and not sharply into that which is free of snow in the summer." (J. B. Auden.)

Glaciers.—It is from the snow above the snow-line that glaciers are derived. The continual accumulation of snow naturally subjects that at the bottom of the heaps to great pressure, which eventually changes the character of the accumulation completely. As the snow becomes more and more pressed upon by the weight of the overlying masses, it loses its granular nature. The particles gradually cohere, forming a firmer mass, called **névé** or **firn,** which represents the intermediate stage between snow and ice (Fig. 127). Finally, the increased pressure lower in the mass causes the formation of a compact blue ice which slowly moves down the mountain slope as a glacier.

" In Arctic regions much of the ice remains permanently in the form of névé, since the temperatures are so low that regelation is not

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* The formation of snow is described in Chapter XIII.

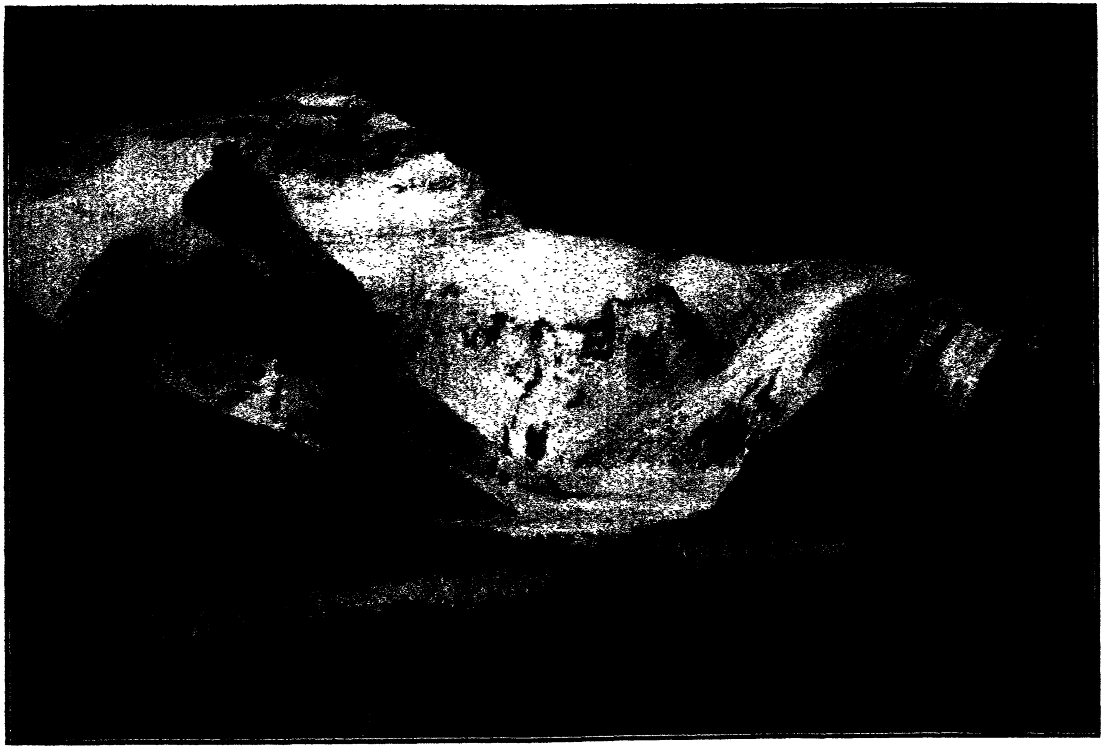

FIG. 127.—View of Mount Everest, 29,002 feet, showing névé at the head of the glacier in the valley. (With the permission of the Director, Geological Survey of India. Photo by A. M. Heron.)

possible and thaws seldom occur. In the Alps and Himalaya, on the other hand, the névé ice changes quickly into glacier ice." (J. B. Auden.)

It is not difficult to understand why such a movement of the glacier should take place when it is remembered that the whole process occurs on the slope of a mountain down which any mass would naturally fall if free to move. It is true that the force of adhesion between the ice and sides of the valley has to be overcome, but the force from behind, caused by the weight of the ever-increasing mass of snow, is great enough to overcome this adhesion.

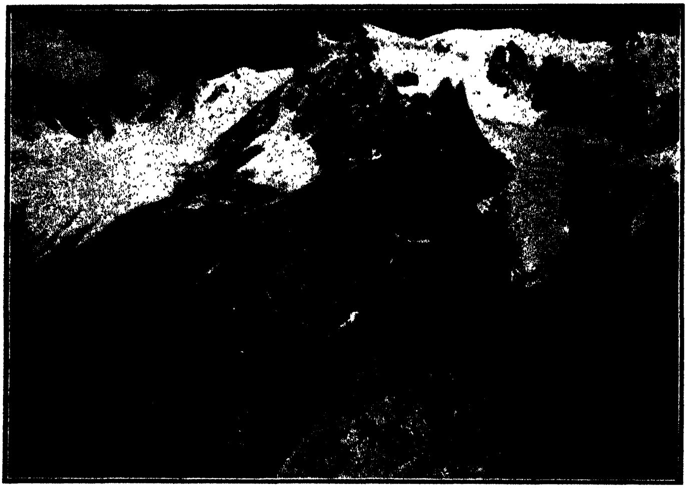

FIG. 128.—Hanging glaciers, near Skoro Lee, Baltistan. (With the permission of the Director, Geological Survey of India. Photo by J. B. Auden.)

" **Ice Sheets** are great accumulations of ice that cover whole continents, hills and valleys alike. Only the highest mountains stand out of the ice as **Nunataks**, an Eskimo word meaning islands of rock surrounded by ice. Such Nunataks are well seen in Greenland and the Antarctic. The thickness of the ice in such ice sheets varies from about 2000 feet up to 8000 feet and it has been calculated that if all the ice were to melt, then the level of the oceans would rise by

80 feet. Much of Bengal would be flooded under such conditions. During the Pleistocene period, ice sheets covered northern Europe, Canada and the northern part of the United States. Since that time the climate has changed, and the main ice sheets are confined to Greenland and the south pole." (J. B. Auden.)

Glaciers as rivers of ice.*—Just as rivers can be looked upon as the drainage of the rainfall in a district, so glaciers may be regarded as a system of drainage by which the snow-fall above the snow-line is removed. But the similarity between the two may possibly be continued to other aspects. Glaciers move from high levels to lower in the same manner as rivers, though, as the one is liquid (water) and the other a solid with the properties of a fluid, the rate of movement of a glacier is very much smaller. Whereas the rate of flow of a moderately quick river is about one to two miles per hour, and of a torrent as much as 12 to 16 miles in the same time, a glacier moves only a few feet or inches in a day. Thus " a hut that was placed upon the Untaraar glacier in Switzerland moved 4712 feet in 14 years, at an average rate of 330 feet per year "—not quite 11 inches a day. The Mer de Glace near Chamonix has an average rate per day throughout the summer and autumn of 20 to 27 inches in the centre, and from 13 to 19½ inches near the sides.† The glaciers of Greenland are more rapid, however ; that of Jacobshavn on the west coast has a rate varying from 48 to 75 feet in the 24 hours. The difference in the rate of motion of the glacier at the centre and at the sides was observed by Tyndall in the case of the Mer de Glace, and is characteristic of glaciers, and constitutes another likeness between them and rivers (p. 168). In both cases where the friction to be overcome is greatest the velocity is least, and clearly this is at the bottom and sides.

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* " Glaciers are slowly moving bodies of ice which occupy valleys in mountain ranges. It is often said that glaciers are rivers of ice, but the motion of a glacier differs in some respects from that of a river which has been photographed in slow motion, so that the usual definition is not strictly correct." (J. B. Auden.)

† " Sometimes the evidence for movement is more dramatic. In 1820 three climbers fell into a crevasse on the Bossons glacier high up upon the side of Mont Blanc. Their bodies began to appear at the snout of this glacier between 1861 and 1865, 41-45 years after the accident. Professor Forbes, having previously determined the rate of motion of the Bossons glacier, was able to predict within a year when the bodies would first make their appearance." (J. B. Auden.)

Proofs of a glacier's motion.—Although the movement of the glacier is so slow as to be undetected by the eye, nevertheless this variation in the motion of different parts of the glacier can be demonstrated in the following ways :

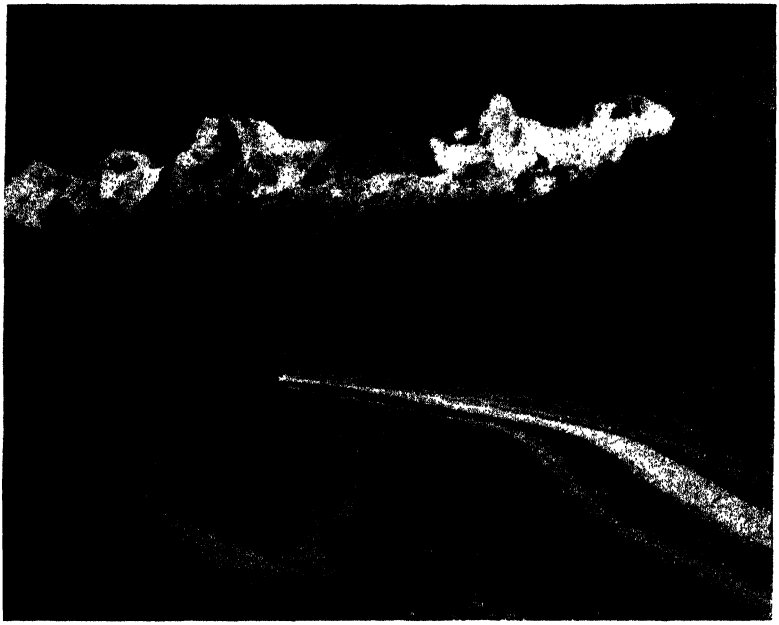

FIG. 129.—Biafo glacier, Baltistan. Longitudinal glacier with tributary transverse glacier. Snow line at about 16,000 feet. Karakoram peaks 22,000 to 24,000 feet in height. (With the permission of the Director, Geological Survey of India. Photo by J. B. Auden.)

(1) If a row of stakes be driven into a glacier in a straight line, after a time the middle stakes will be seen to have travelled farther down the valley than those at the sides.

(2) The fissures (crevasses) across the glacier are curved, the curve being convex towards the valley mouth.

(3) Lateral moraines are maintained as such partly by the slower movement at the sides of a glacier.

Behaviour of glaciers in moving downwards.—The exact causes producing the movement of a glacier cannot be said to be known fully. It has been suggested that ice behaves as a very viscous liquid, and slowly flows down the valley ; but others maintain that a continual melting and breaking of the ice goes on, which is followed by the freezing together, or **regelation,** of the separated parts, and that this is sufficient to account for the small amount of yielding experienced.

When a glacier moves valleywards, it has sometimes to travel over a very uneven floor, and some part may get wedged up against an outstanding projection and be prevented from moving ; while the upper parts, being still acted upon by the weight of the accumulated snows above, and being free to move, slide over the impaled portion. This will interfere with the regular movement of the glacier, producing something comparable to an eddy in a river.

A sudden drop in the slope of the mountain side, which would in the case of a river produce a waterfall, may cause a break in the glacier. This fissure may in the first instance be nothing more than a crack, but the onward passage of the lower portions will result by-and-by in the formation of a wide gap known as a **crevasse.** These crevasses sometimes reach quite to the bottom of the glacier but, whether they do so or not, there is always a tendency for the pressure, which acts on all sides, to efface the rent.

The glacier will continue its existence and downward motion until the temperature becomes high enough to melt the ice, when it will terminate and from its **snout** or end there is generally a stream of muddy water, which may be the source of a river. Thus the Bhagirathi river has its source in the ice-cave of Gaimukh, which is the snout of the Gangotri glacier in the Himalayas beyond the peak of Kedarnath. It will be evident that a prolonged addition to the snow accumulation towards the summit of the mountain will increase the supply of ice at the valley end, and in that case the amount of heat will of necessity have to be greater to effect the liquefaction of the ice ; this increased amount of heat can be obtained lower down only, so that the glacier will become longer. A diminution in the supply of snow will have a contrary effect.

Work done by glaciers is only mechanical.—The mechanical work which a glacier accomplishes is important, and can be considered under two heads—(1) its carrying work; (2) the erosion it effects.

The work of transport is performed in a different way from that of rivers, for most of the detritus is carried upon the surface of the glacier and seen in the form of lateral and medial moraines (Fig. 129). The ice cannot, like water, hold material in suspension, though frozen into its mass will be the fragments of rock which were mixed with the snow from which it was formed. Corresponding to the larger materials which are pushed along the bed of a river, there is in the case of the glacier a certain amount of detritus at the bottom

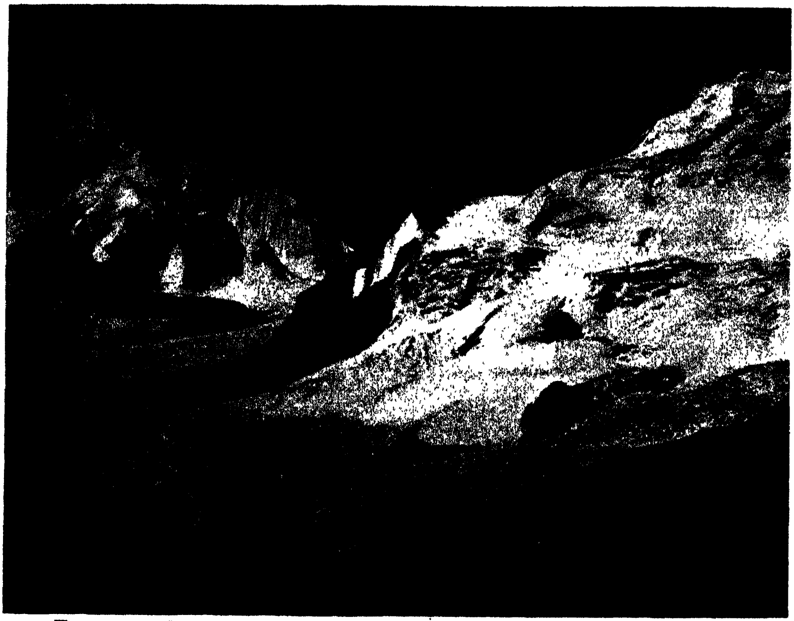

FIG. 130.—Ice field on steep mountain slope interrupted by ice falls. The glacier joins at the bottom left of the picture. Nepal Himalaya. (With the permission of the Director, Geological Survey of India. Photo by J. B. Auden.)

which has got there by tumbling down crevasses or been torn off the floor of the valley by the grinding action of the moving ice. The rock fragments which accumulate on the surface of a glacier are known as **moraine** stuff; this is not distributed irregularly, but arranged more or less definitely along the sides and middle, constituting **lateral** and **medial moraines** respectively. The medial moraines are the result of the union of two glaciers, for when this takes place the right of one and the left lateral moraine of the other unite to form a larger single medial moraine. Should a glacier receive several tributaries there will be more than one medial moraine formed, the number indicating the number of tributaries received (Figs. 129 and 130).

In travelling over uneven ground there will be a tendency for the detritus, which has reached the bottom through the crevasses, to accumulate in places where projections occur. These accumulations constitute what are termed **ground moraines** or perhaps **moraines profondes.** The débris which accumulates at the snout of a glacier makes what is commonly called a **terminal moraine.**

If for any cause a diminution in the volume of a glacier takes place, some part of the lateral moraine will be deposited on the side of the valley. This deposit often contains blocks of some size, and when these are left in such a stranded position they are spoken of as **perched blocks** or **erratics.** During what is called the **glacial epoch** of geological time (Pleistocene age) ice sheets and glaciers were much more widespread over the northern hemisphere than they are now, and it is common in some countries to meet with perched blocks far removed from any existing glacier, but without doubt deposited in this manner.

" It is doubtful if the Indian Peninsula was ever under permanent snow during the Pleistocene Ice Age, but it is known that the Himalayan glaciers formerly descended much lower than they do now. In Sikkim there are terminal moraines at 8500 feet in the Lachung valley, whereas few glaciers in that region now descend below 13,000 feet. In the Garhwal Himalaya glacial moraines have been seen down to 10,000 feet, as at Badrinath and Gangotri. In Kashmir and Baltistan the modern glaciers are found at lower levels than elsewhere in India, from 8000 to 10,000 feet, but during the Ice Age there must have been glaciers on the Pir Panjal range overlooking Srinagar which caused moraines to be formed as low as 5000 feet." (J. B. Auden.)

Material deposited by the Pleistocene ice sheets in Great Britain and now found in various parts of the country concealing the rocks below is known as **glacial drift.**

Glacier tables.—The ice at the surface of a glacier is disappearing continually both by melting and by evaporation. A mass of rock upon the surface of the glacier, however, will protect the ice under it from the heat of the sun. The result is that a pillar of ice, capped with the protecting rock, is often left standing above the general level of the glacier; this formation is spoken of as a **glacier table.** The pillar of ice slowly disappears and eventually becomes too frail to support the rock, which falls.

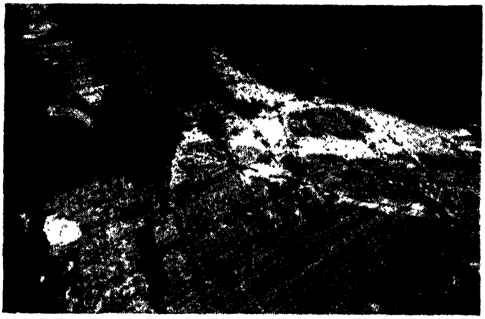

FIG. 131.—A striated surface of slate, Argyll, Scotland: (By courtesy of the Director, H.M. Geological Survey, London).

A glacier's work of erosion.—The earth and stones which often find their way down crevasses to the bottom of a glacier become frozen firmly into its mass, and as the glacier moves slowly down the mountain side the rock fragments are ground against the rocky bed, becoming themselves characteristically smoothed and scratched, and also causing the same result upon the beds over which they pass. This polishing effect is so great that even the hardest rocks become grooved and striated. The motion of the glacier being generally regularly downwards, these scratches usually indicate the line of motion, and stretch lengthwise down the valley (Fig. 131).*

The water formed from the local melting of a glacier collects on the surface, but often finds its way down one of the numerous crevasses, carrying with it a considerable quantity of the moraine detritus. This water finally gets under the glacier, and in many cases, by the help of the stones it carries with it, forms a **glacier-mill,** which may in time erode a **pot-hole** or so-called **giant's kettle.** As in the case of rivers the largest amount of glacial erosion will be effected in those cases where the rocks are soft. It is sometimes indeed sufficiently extensive to form considerable hollows, which on the retirement of the glacier often become filled with water, forming *tarns* or *lakes* (p. 208). It is thought by some that the lake at Naini Tal is due to the scooping out of the limestone floor of the valley by an ancient glacier.

Results of glacial action.—It is quite possible to tell where glaciers have been from the permanent record they leave behind. It will be useful to summarise the evidence the existence of which in any country can be taken as proof of the previous existence of glaciers.

(1) Glaciated **hills** are **rounded** in contrast with the irregular outlines of peaks in the sculpturing of which glaciers have not taken part.

(2) Glaciated **valleys** are typically flat-bottomed or **U-shaped** (Fig. 127), whereas valleys formed by rivers only are typically V-shaped (Figs. 111 and 113). A main valley recently deepened by a glacier is as a rule at a markedly lower level than its tributary valleys (which are therefore called " hanging valleys ") ; so that tributary streams join the main river by waterfalls from the " shelf " or " shoulder " where the continuity of the slope of the side of the main valley is broken.

(3) The upper end of a recently glaciated valley is frequently distinguished by a flat, " arm-chair "-like area called a *cirque*, *corrie*, *cwm* or *combe*, in which a lake often occurs. The precise mode of formation of a cirque is still rather uncertain.

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* When by a general increase of temperature the glacier as a whole melts, its bed may be seen to have assumed the form of smooth undulating prominences. These rounded mounds are called *roches moutonnées* from their fancied resemblance to a well-dressed fleece or one of the wigs formerly styled *moutonnées* (Prof. G. A. J. Cole).

(4) The heap of materials (the *terminal moraine*) formed at the glacier's snout and stationary for some time may be large and impound water to form a tarn or lake. This terminal moraine contains striated stones and is easily recognised.

(5) The smooth glaciated rocks which formed the bed of the glacier are unmistakable. The striations found thereon are more or less parallel, and show the direction of the glacier's flow (Fig. 131).

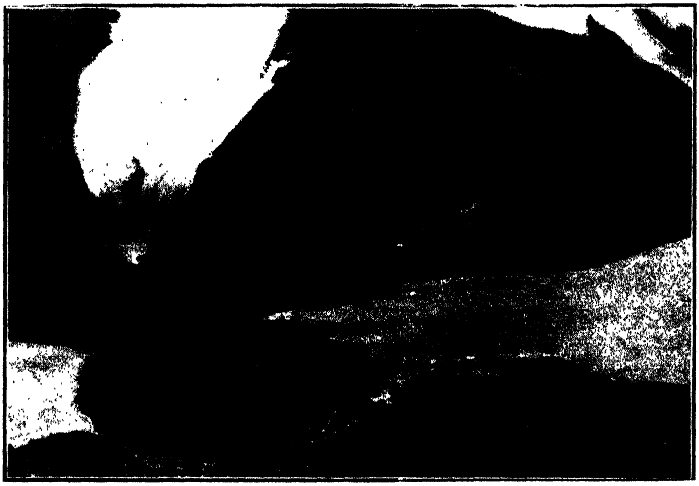

FIG. 132.—Lake dammed by terminal moraine of retreating Chombu glacier, Sikkim. The lower lake is dammed by a glacier descending from another valley. (With the permission of the Director, Geological Survey of India. Photo by J. B. Auden.)

(6) Perched blocks often occur on what was originally the side of the glacier. They are quite dissimilar in nature from the rocks on which they rest.

(7) The material at the bottom of the glacier (moraine profonde) is strewn irregularly over the site of the glacier, and contains characteristically marked stones, the mixture of " glacial drift " constituting **boulder clay.**

Glacial dams.—" Mention should now be made of lakes that have been formed by the blocking of one valley by a glacier which has descended down another valley. The danger is worst when a major valley is occupied by a river and a minor tributary valley by a glacier. These steep tributary glaciers are sometimes subject to sudden advances, which may be sufficient completely to block up the main valley and to form a lake. The lake either increases in depth until it tops the glacier dam over which it escapes, or it empties itself gradually through a tunnel formed in the ice. Sometimes, however, the glacial dam breaks down suddenly as a result of excessive ablation or because the pressure of the glacier against the main valley wall has become less. The lake is emptied suddenly and disastrous floods occur lower down the valley. Many of the Indus floods are due to the bursting of a lake formed in the Shyok valley by the Chong Kumdan glacier." (J. B. Auden.) Fig. 192.

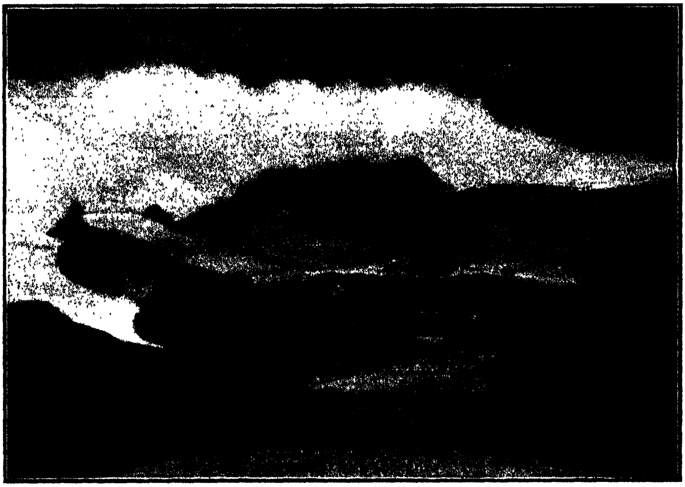

FIG. 133.—Chombu peak and glacier, Sikkim. Type of transverse glacier broken by ice falls and ending in a lake. The same lake is seen in Fig. 132, dammed by an old terminal moraine of the now retreated glacier. (With the permission of the Director, Geological Survey of India. Photo by J. B. Auden.)

Icebergs are broken off from glaciers which reach the sea in polar regions.—When a glacier in polar regions reaches the sea level, it moves on into the water, where parts break off and float away as **icebergs**. Evidently the iceberg is frozen fresh-water and was formed on land. Ice is lighter than water, its specific gravity being 0·918 compared with that of pure water at 4° C. The ice consequently floats upon the water, and as its density is very near that of water, only about one-tenth of the iceberg is above the sea level, the other nine-tenths being below. As the iceberg travels into warmer latitudes it gradually melts, dropping into the sea the materials which were frozen into it when it existed as a glacier. Icebergs are often of a great size, being sometimes several miles in circumference and rising to a height of 700 feet above the water. They are rarely found south of latitude 40° N. or north of latitude 35° S.

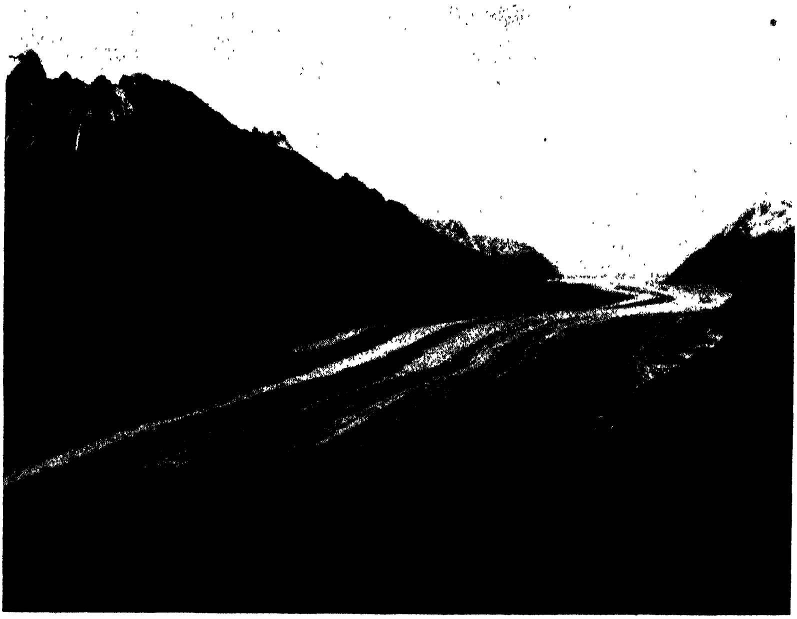

FIG. 134.—Biafo glacier, Baltistan. Length 36 miles. Gradient over most of its course 212 feet per mile. Note medial and lateral moraines. (With the permission of the Director, Geological Survey of India. Photo by J. B. Auden.)

The Pleistocene and Gondwana Glacial Epochs.—The period at which the glaciers and great ice sheets existed in Britain is known as the Pleistocene Glacial Epoch or the Great Ice Age. The Pleistocene Glacial Epoch occurred quite recently—as a geologist estimates lapse of time, though judged by everyday standards its remoteness, possibly half a million years ago, is immense—so that the effects which that great event had upon the features of hill and dale have not been effaced by denudation. It is quite evident that at that time most of the northern hemisphere was like modern Greenland in being covered by a thick sheet of ice, above which only the summits of the peaks protruded (*Nunataks*). The signs of glaciation detailed above (p. 207) are still to be recognised in almost all parts of the British Isles north of the latitude of the Bristol Channel, and particularly in the hilly areas of the Highlands of Scotland, the Lake District, Wales, etc. Rocks brought by glaciers from Norway are found near Flamborough Head and in the Fen district, and boulders of Ailsa Craig granite occur as far south as the Midland counties of England. In India the glaciers of the Himalayas were then much more extensive and came down to lower levels than they now

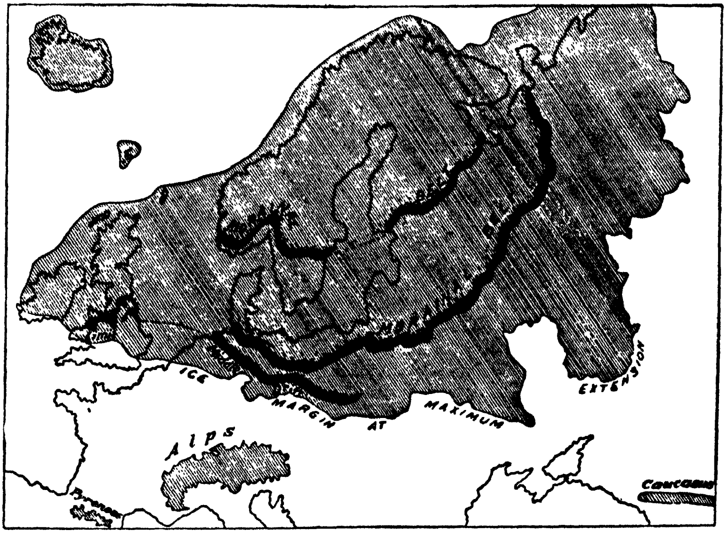

FIG. 135.—Map of the glaciated and non-glaciated areas of northern Europe. The strongly marked morainal belts respectively south and north of the Baltic depression represent halting places in the retreat of the last continental glacier (compiled from maps by Penck and Leverett).

do. Even to-day the Fedchenko glacier in the Pamirs is 42 miles in length, while in the Karakorams, according to Mr. J. B. Auden, there are five glaciers over 30 miles in length. Some of these appear from a distance to be enormous roads (Fig. 134) on account of the gentle and even slope of their floors. Large glaciers, such as the Fedchenko in the Pamirs and the Biafo in Baltistan, are in places 2000 feet thick (deep).

Geologists—W. T. and H. F. Blanford—working in the Indian peninsula, about Talchir in Orissa, discovered as long ago as 1855-6, evidence of glacial débris resembling ground moraines indicative of an Ice Age in this country, nearly 200 million years ago, in the Gondwana period. Since then extensive discoveries have been made of this ancient glaciation in the Indian region, showing that ice sheets and glaciers moved northwards from the Central Provinces towards Rajputana, and that icebergs floated away over the Punjab and part of Kashmir and dropped boulders of Rajputana rocks in the Punjab Salt Range area. Many of these boulders are not only striated but also faceted. A true **glacial pavement** was also found in the Irai river in the Chanda district, under glacial boulder beds, and in every way resembling the striated rock surfaces of recent glaciations called **roches moutonnées**. It is now known that this Gondwana

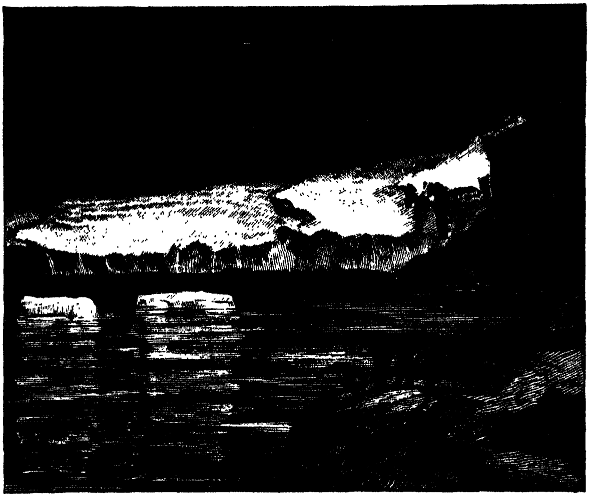

FIG. 136.—The formation of icebergs.

glacial period was very extensive in the southern hemisphere and included South Africa, South America, and parts of Australia under its ice sheets and glaciers.

By carefully noting the position of erratic blocks and where possible ascertaining the locality of the parent rocks, and observing also the directions of the glacial striae, geologists have been able to prepare maps showing the centres of glaciation and the movements of the glaciers both of the Pleistocene Ice Age of Europe (Fig. 135) and also of the Gondwana glacial period for India, South Africa, South America, and Australia in a less certain way.

EXERCISES ON CHAPTER VII

1. Why do some rivers form deltas and others flow into estuaries? Give examples of each.

2. (*a*) What is meant by (i) the sources of a river, (ii) the bed of a river, (iii) a gorge, and (iv) the right bank of a river?

(*b*) If the bed of a river is made of rounded pebbles, how did they get there, and how is it that they are rounded?

3. Describe carefully how rivers act (i) as denuding agents, (ii) as depositing agents. Illustrate your answer by reference to some one continent whose geography is known to you.

4. Describe, with diagrams, various conditions which may determine the formation of springs.

5. What is a bore? Give examples from Bengal and Burma.

6. Give a short account of the action of rain as an agent of denudation in the Assam range, on the Bihar plateau, and in the hills of Baluchistan.

7. Describe the effects produced by a river (*a*) in the upper and steeper part of the course, (*b*) in the lower and flatter part.

8. What explanation can you give of the fact that one bank of a river occasionally is sloping while the opposite one is steep-sided? Of which portion of a river valley is this feature most characteristic, and for what reasons?

9. Trace the course of a typical river from source to mouth, describing the ways in which it might modify the surface of the earth. Illustrate your answer by reference to the Narbada, Mahanadi, and Ganges rivers.

10. Describe a Himalayan glacier, *e.g.* Biafo or Gangotri. Compare it with the Greenland ice sheet. What evidence is there to show that glacial conditions formerly prevailed in Britain?

11. Give an account, with diagrams, of the structure of an artesian basin.

Explain how at one time Quetta was evidently supplied with water from artesian wells.

12. Describe how a plateau is reduced by denudation to a plain, and give actual examples of different stages from the Deccan in the upper valleys of the Kistna and Tungabhadra rivers.

13. Give an account of the way in which a river forms a delta. Discuss the distribution in Bengal of the deltaic deposits of most importance to man.

14. What conditions determine the amount of sediment brought down by a river?

15. What is a cañon and under what conditions may it be formed? Give an Indian or Afghan example.

CHAPTER VIII

VOLCANOES AND EARTHQUAKES

20. VOLCANOES AND VOLCANIC ACTION

1. Distribution of volcanoes.—Examine Fig. 142. Are the volcanoes shown on it scattered irregularly, or do they lie along lines or bands? Are they most abundant near or far from the sea? Compare the borders of the Atlantic and of the Pacific Oceans in respect of the number of volcanoes. How many volcanoes are on islands? Is there any special abundance of volcanoes along mountain ranges?

The internal heat of the earth.—Both volcanoes and earthquakes may ultimately be traced to movements which result in shrinkage of the earth's crust, due to loss of the internal heat of the earth. This internal heat may be regarded as the relic of a former molten condition of our planet. That the interior of the earth is at a much higher temperature than the crust is concluded from such observations as the following:

(*a*) The materials—gases and molten lava—ejected from volcanoes are at a very high temperature. Those substances which are liquid at ordinary temperatures, such as water, are emitted in a highly heated gaseous condition. Those which are solid at the temperature of the earth's surface are often ejected as lava in an incandescent liquid state. The inference is that the earth's crust at the depth from which they are derived is at a very high temperature.

(*b*) The temperature of the rocks rises the deeper we descend, and, presumably, as the centre of the earth is approached. The rate of increase met with in deep mines and borings varies in different places for a variety of reasons, such as the different specific heat and conducting power of the rocks. An average result in Europe, for accessible depths, is an increase of 1° F. for a descent of about 55 feet, or, roughly, 100° F. per mile.

(*c*) The temperatures of the waters of artesian wells, hot springs and geysers, is higher than that of surface waters. The temperature of the water in the hot spring at a depth of 2900 feet in the Ridgeway boring for oil in England was 120° F., the water of the hot springs at Bath is 120° F., that of the spring in the sands at Tatapani in the Sutlej north of Simla is nearly 140° F., and other hot springs in India have similarly high temperatures, and it is said that some of the geysers of Iceland are 190° F.

Definition of a volcano.—An active volcano is an orifice or vent, perhaps a crack, connecting the surface and the molten interior of the earth. The definition still given in some geography books that it is " a burning mountain " is of course wrong. Of *burning*, in any correct sense of the word, meaning combustion, there is none. Nor need a volcano be a mountain. Although the accumulation of the ejected materials round the hidden vent or hole in the crust often causes a hill to be built up, there is sometimes no such mould formed, indeed in some cases there is an actual depression. There are examples of cauldron-shaped up-wellings of molten lava, particularly those of Hawaii and Samoa. The definition becomes more complete if we add that from the hole in the crust are ejected, sometimes quietly but often with explosive violence, various materials which are generally at a high temperature. Our definition thus becomes :

A volcano is a vent, perhaps a crack, connecting the exterior and interior of the earth ; from it are ejected, often with explosive violence, various materials, which are generally at a high temperature.

Kinds of volcanoes.—Volcanoes may be divided into classes depending upon the frequency of the eruptions which take place. Barren Island, in the Bay of Bengal, may be considered as an active volcano—the only one at present in the Indian region. There are no volcanoes at all in the Himalayas or in the Indian peninsula. **Active** volcanoes are those from which an eruption can be expected at any time. If there is no cessation of activity of some degree, we have a *constant* volcano, like Stromboli. If the eruption is followed more or less regularly by a period of rest, such a volcano is called *periodic*, like Vesuvius, where, after a great eruption in 1872, there were only disturbances of minor importance until the next great eruption in 1906. If the period of rest extends into a great number of years, and is then followed by an eruption, the volcano is described as **dormant**—thus Vesuvius, which was thought to be extinct, erupted in A.D. 79, when it destroyed the Roman towns of Pompeii and Herculaneum, and then lay dormant till the outbreak of 1631; the next outbreak was in 1872 and the last a few years ago. In those cases where the activity seems to have ceased altogether, we have **extinct** volcanoes, such as Popa and Hawshuenshan in Burma and Koh-i-Tuftan and Koh-i-Sultan in Persia on the borders of Baluchistan.

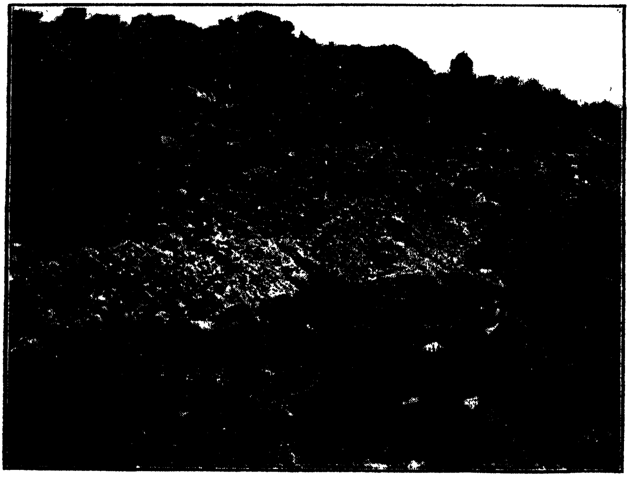

FIG. 137.—Nicolosi, Etna. Common scoriaceous lava. (From a photograph by Dr. Tempest Anderson.)

Materials ejected from volcanoes can be classed under three heads, according to the physical conditions in which they are emitted, *viz.* *gaseous*, *liquid*, *solid*—all in a heated condition.

The chief **gas** given off from a volcano is *steam*. This vapour is evolved in enormous quantities. The air round the volcano becomes so saturated with moisture that the steam accumulates as clouds of great extent, and is condensed into torrents of rain.

In addition to steam, there are also emitted *carbon dioxide, sulphur dioxide, hydrochloric acid gas,* with others, though in very small quantities only.

The **liquid** material which is given off by a volcano is known as **lava.** Its degree of fluidity depends upon its chemical composition. Lava generally cools very slowly, after a thin crust, which looks like clinker, has once been formed. When an acid lava cools quickly, a glassy rock, like *obsidian,* is the result. The flow of the liquid lava below, after a crust has formed on the surface, causes the characteristic "corded" appearance shown in Fig. 140. Steam and other gases are given off in cooling, and these gases in escaping often cause the lava to be filled with holes and give rise to a *vesicular* rock of scoriaceous appearance.

Pumice is formed by the expansive force of steam inside acid lavas. From the cindery appearance (Fig. 137) which some cooled lava streams have, the term *scoriaceous* has been derived, and is often used to describe the volcanic rocks so formed. Lavas sometimes take a beautiful columnar form on cooling, like the basalt columns of the Giant's Causeway and Fingal's Cave. This columnar structure, which is often seen in exposures of the Deccan basalts, is shown in Fig. 138.

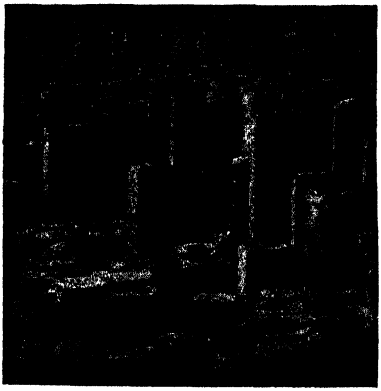

FIG. 138.—Ordinary columnar structure of basalt (Giant's Causeway).

The **solid** materials ejected from volcanoes are usually of a fragmental kind. They include bombs, lapilli, and dust. *Bombs* are lumps of lava forced off the ascending liquid column by the current of issuing steam. They are whirled round and round in the air, and get a roughly spherical form. They cool rapidly on the outside into a glassy shell, but inside are much more crystalline. *Lapilli* are angular fragments of lava similarly forced off by the issuing steam. The larger pieces are known as *scoriae,* the term lapilli being reserved for pieces varying from the size of a pea to that of a marble.

Cause of volcanic action.—Volcanic action is probably the result of several causes, all of which are responsible to some extent for the effects to be described below. Until quite recently explosions caused by superheated steam were regarded as of much the greatest importance. From the bottom of the sea and lakes, from the surface of the land everywhere, water is passing continually into the crust of the earth. This percolation goes on through every crevice. Sometimes by its own weight, and often when the cracks are only minute, by capillary attraction, an enormous amount of water must reach the interior, either directly or when the rocks containing water, as moisture, are depressed to great depths in the earth's crust. But whether such water, or water-containing rocks, really reach a highly heated zone seems questionable. Whatever its source, water is present in most lavas, and must be converted into steam as the lava approaches the surface. At a depth of three miles the temperature will be higher than the boiling point of water at the sea level, and at greater depths it will be much higher because the pressure to which the water is subjected in the earth's interior is very great. Steam will be formed continuously, and thus there will be more and more vapour forced into a given space, which will cause the pressure of the steam to become greater and greater. Just as in a boiler the pressure of the enclosed steam can only be increased safely up to a certain point, beyond which a further addition to the pressure will cause the material of the boiler to break, resulting in an explosion, so the pressure of the steam—or perhaps its dissociated gaseous elements, oxygen and hydrogen, in explosive proportion and highly heated—enclosed within the earth's crust can only go on without an explosion so long as the pressure of the gases upwards is less than that of the weight of the rocks downwards. When the pressure of the steam, or superheated gases, is increased beyond this point an explosive **volcanic eruption** presumably takes place. Either a new crack is formed in the earth's crust through which volcanic materials are ejected, or the solidified lava in an old volcano vent is forced out violently and a new eruption takes place from an old volcano.

This explanation of volcanic action, however, does not account for the quiet up-welling of molten lava in cauldron-like craters, so that there must be factors to be considered which are not yet fully known. Volcanoes occur in marked abundance along certain great lines of folding of the earth's crust, and on the margins of regions which show signs of recent elevation or depression by dislocation. This fact confirms a theory that the subterranean movements and ultimate ejection of molten matter are due to the crumpling and rearrangement of the rock masses. It is not to be forgotten, however, that volcanoes generally occur where these tectonic lines—of folding or dislocation—lie in the sea. The importance of access of sea water to rocks heated by shearing thus becomes significant, but there are places, as in Persia, where this relationship is not so evident. The lava, however it may be formed in the earth's crust, naturally takes the path of least resistance, which is often a volcano already in existence.

A volcanic eruption.—The order of events throughout a violent volcanic eruption is by no means uniform, in fact there are great differences, but there are many phenomena which generally occur. In the eruption, as we shall describe it, no particular instance is referred to, but the chief events are narrated in the order in which they would probably happen. When the neighbourhood has been quiescent for some time, the advent of a new disturbance is heralded generally by loud rumbling noises from the earth's interior, which are often followed by earthquake shocks (p. 231). There may be at this time, too, a fairly universal interference with the direction and nature of the streams, as well as of the sea level, in the neighbourhood.

These premonitory signs last for varying periods, and are followed by an increase in the amount of steam which escapes from volcanic vents in the district, as well as by a raising of the level of the lava in the throat of such vents. Then a mighty explosion takes place. There is a sudden and violent escape of a huge volume of pent-up steam. The force with which it issues is so tremendous that it scatters lumps, which it tears from the sides of the throat, in every direction, propelling some of them far up into the air. Cases are on record where the expansive force of the issuing steam has been so great that the cone accumulated during previous eruptions has been blown into minute fragments. The particles formed in this way constitute the volcanic dust which is given off in great quantities.

The clouds of steam often take the appearance of flames, and are accountable for the popular idea of a volcano. The molten lava which now fills the neck of the volcano is at so high a temperature that it is luminous. The light it emits is reflected from the banks of steam above, and they themselves are transfigured, appearing as blazes of light. The water vapour with which the atmosphere is saturated becomes condensed and falls as torrents of rain. The falling rain brings down with it the volcanic dust, and together these result in the formation of streams of volcanic mud which flow down the side of the cone. The mutual friction of the particles of vapours and dust causes the clouds to become charged electrically and results in the thunder and lightning which add to the weirdness of the scene. The showers of scoriae, lapilli, and dust cause a continual addition to the size of the cone. The dust, too, in the presence of winds, is carried huge distances, sometimes many thousands of miles.* Finally, we must mention the streams of lava which begin to flow when the liquid rocks from the interior well over the sides of the crater's mouth.

Tambora or Tumboro, a volcano in the island of Sumbawa (200 miles east of Java), blew up in 1815 and is said to have lost one-third of its height, although it is still 9000 feet high. The darkness occasioned by its ashes was so profound in the daytime in Java that nothing equal to it was witnessed on the darkest night, and some of the particles fell as far east as Banda and Amboyna, 800 miles away. The cinders floating on the sea to the west of Sumatra formed a mass 2 feet thick and several miles in extent through which ships forced their way with difficulty.

When Krakatoa or Krakatau blew up in August, 1883, it was a volcanic cone 2700 feet high in an island 5 miles long by 3 miles wide in the Straits of Sunda, between Java and Sumatra. It was clothed with the luxuriant vegetation of a tropical forest. In May several earthquake shocks and hollow reverberating sounds were noticed at Buitenzorg and Batavia, 100 miles away, and a ship passing about the same time noticed a dome-shaped mass of vapour, mingled with smoke of a dark grey colour, rising from the lower part of the island. Activity continued in June and July, but it was not till late in August that the explosion occurred. The volume of ashes and pumice was so great that ships within a distance of 20 to 30 miles were in absolute darkness after 9 a.m. on the 27th, and in September the sea at Lampong bay, 40 to 50 miles to the north, was still covered with pumice 14 feet thick.

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* *Barren Island.*—As already stated, there are no active volcanoes in India, except that of Barren Island, under 2 miles in diameter and roughly 900 feet high, in 12° 15′ 30″ N. latitude and 93° 49′ 20″ E. longitude. This conical hill, surrounded by a ring-shaped mountain, emerges from deep water in the Bay of Bengal; landing is very difficult except on the S.W. side and there is no anchorage. At the summit of the cone, termed the crater, there is an orifice through which hot, sulphurous gases are emitted. In 1795 Captain Blair visited the island and found the central cone throwing out red-hot stones of several tons weight and enormous volumes of smoke. In 1803, when the island was visited by Horsburg, explosions occurred every 10 minutes or so, followed by the emission of columns of black smoke which went up to a considerable height, and at night a fire of considerable extent became visible on the east side. Both the central cone and the outer ring consist of volcanic débris, including vesicular lava and pumice, which reaches the sea at one side where the ring is broken.

The great explosion of the morning of the 27th August produced a concussion of the atmosphere that caused the barometer to oscillate through half to one inch in a minute, and was propagated as a wave of atmospheric disturbance round the world, repeating its passage at intervals of thirty-seven hours, as it completed the circuit again and again to not less than three and a half revolutions, since seven transits of the wave were recorded in Europe and America. For more than six months after the eruption, the loftier strata of the earth's atmosphere remained charged with impalpable volcanic ash, in such quantity as to cause an anticipation of the morning dawn, and a prolongation of the evening sky glow, recorded in all parts of the world up to the end of 1883 and well into 1884. (H. F. Blanford.)

The events of the eruptions in the West Indies, those of the Soufrière mountain in St. Vincent, of Mont Pelée in Martinique, which took place from May to July, 1902, and of Matavanu in Savaii (Samoa), which began in August 4, 1905, differ in some respects from those outlined above. In the case of **the Mont Pelée eruption** (Fig. 139), the most peculiar feature was the avalanche of incandescent sand and the great black cloud which accompanied it. The preliminary stages consisted of outbursts of steam, fine dust, stones, and torrents of water, which had collected in the crater. As soon as the throat of the crater was cleared and the climax of the eruption was reached, a mass of incandescent lava was blown to pieces by the expansion of the gases it contained, and descended upon the surrounding country as an avalanche of red-hot dust. The torrent of red-hot dust rushed down the slopes of the hill, behaving like a liquid, carrying with it a terrific blast, which mowed down everything in its path, till it reached the sea, when it subsided quietly. The gases were chiefly steam and sulphurous acid ; there was little oxygen in the gaseous mixture, and respiration in the neighbourhood was impossible.

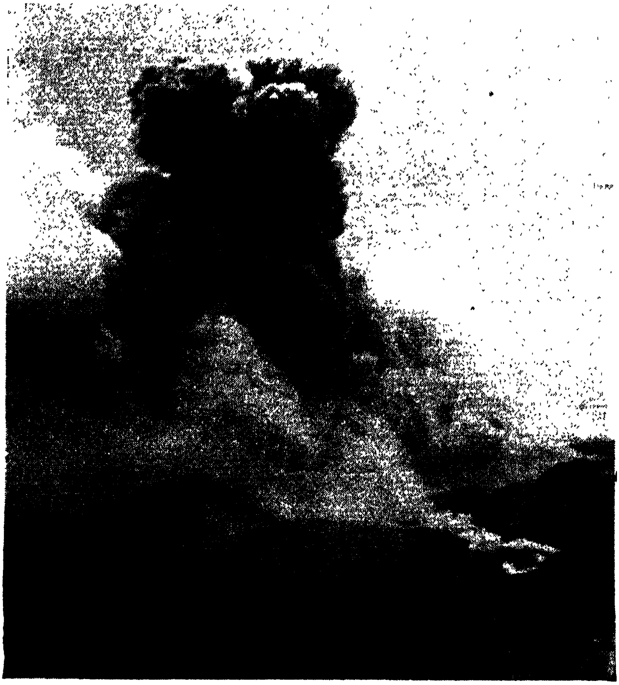

FIG. 139.—Eruption of volcanic dust from Mont Pelée in June 1902.

In a paper by Dr. Tempest Anderson, read before the Geological Society on April 13, 1910, **the eruption of Matavanu (Samoa)** is described in detail. Before the commencement of the eruption, on August 4, 1905, the place where the cone now is was an almost level, elevated plain surrounded by mountains. The cone does not rise high above the surrounding lava fields (Fig. 140) ; only at certain points does it reach a height of 350 feet above them. The bottom of the crater "is entirely occupied by a lake of liquid lava all in rapid motion and of such extreme fluidity that it continually beats in surging waves against the walls, where splashes retain their heat and brilliant colour for some time. The surface is in a constant state of ebullition, though not always to the same degree in different parts. Some of the boilings rise in veritable fountains of incandescent liquid basalt of 10, 20, or even, I think, possibly at times, 50 feet high. The whole mass of the lava is at a brilliant white heat, visible as such even in bright sunlight, but a darker scum is continually forming on the surface, especially where the trade wind blows strongly on it."

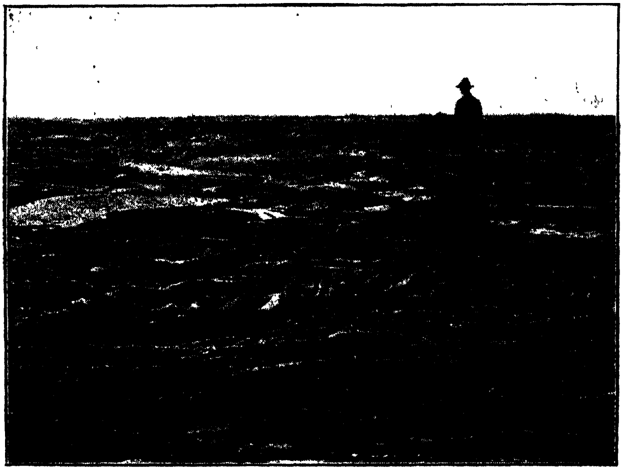

FIG. 140.—Common corded lava from the volcano Matavanu. (From a photograph by Dr. Tempest Anderson.) Dr. Anderson points out that the apparently light colour of the lava in the background is due to reflection, the lava being in reality almost black.

The molten lava reached the sea on December 7, 1905, and had been flowing into the sea, with the exception of one day, since that date. Where the discharges into the sea were most active, "explosions were almost continuous, and the whole was obscured by clouds of steam, from which fragments of red-hot lava and showers of black sand were seen to fall. When the lava was flowing in smaller quantity, explosions were much less noticeable, and the lava extended itself into buds or lobes" (pillow lava). Dr. Anderson pointed out that both Matavanu and Kilauea (in Hawaii) " are of the effusive type, that is, characterised by the discharge of lava very slightly charged with steam and other volcanic gases, and hence little subject to explosive action ; in which respect they contrast strongly with the volcanoes of the West Indies and Central America, where most of the recent eruptions have been highly explosive, and attended with the discharge of a vast quantity of ashes, lapilli and pumice, but little or no lava ".*

Different kinds of cones.—Cones may be described under four heads, viz. :

(1) *Scoriae* or *cinder cones.*
(2) *Tuff cones.*
(3) *Lava cones.*
(4) *Compound cones.*

The plan on which they are all constructed follows the same lines, and it will be desirable first to refer briefly to the *structure of a cone* in general. The materials from which the cone is built up are thrown out from a crack in the crust, which must be regarded as the starting point. These fragments severally describe curves, after the pattern of those of the drops of water from a fountain. In this way a circular deposit of ejected material is formed round the orifice as a centre. As the eruption continues, this heap of fragments increases in height, and the mound slopes towards and from the hole at an angle depending upon the nature of the materials. This angle is called the " angle of rest ". Eventually the inner slopes close in towards one another, and from the outside the appearance is that of a simple conical hill. If, however, by any means the internal structure becomes revealed, it is seen that on every side of the orifice there is a hill, the sides of which respectively slope towards and away from the vent (Fig. 141).

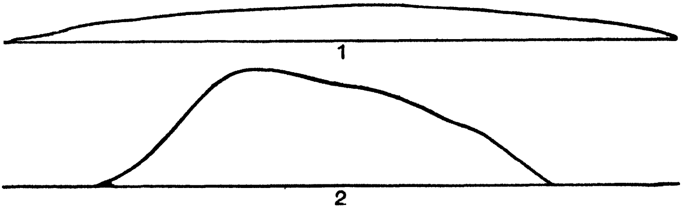

FIG. 141.—Characteristic profiles of lava volcanoes. 1. basaltic lava mountain ; 2. mountain of siliceous lava (after Judd).

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* *Quarterly Journal of the Geological Society*, November 1910.

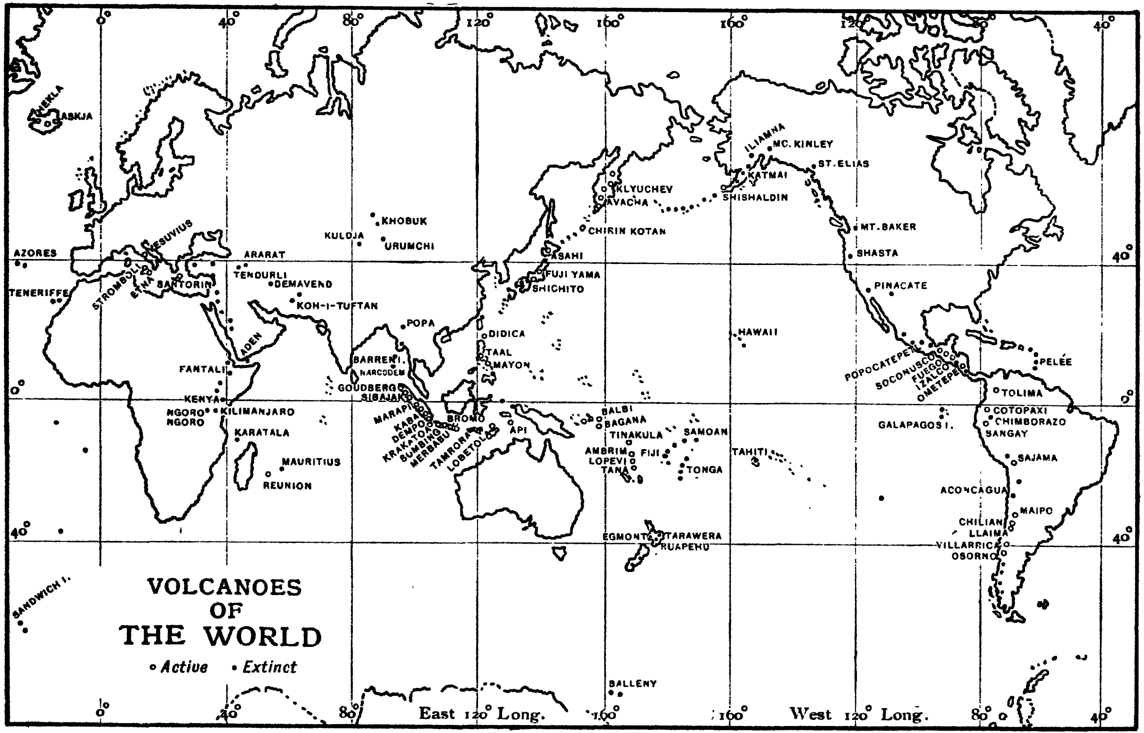
Cinder cones are made of scoriae or lapilli. These are usually of a dark colour, which becomes changed to a reddish hue by the action of the rain upon the minerals they contain. Though, from the loose nature of the materials of which such cones are built, it might be expected they would be washed away by the rain easily, yet, as the extinct cinder cones of Auvergne show, such is not the case. These cones do in time become covered with a soil, but this does not destroy their form. The angle of slope of this order of cone is from 35°-40°, this being the "angle of rest" of such material as scoriae. These cones are generally higher on one side, which side indicates the direction in which the wind was blowing at the time of the eruption. One kind of scoriae cone is made of *pumice*, as that of Campo Bianco, in the island of Lipari.

Tuff cones.—Tuff is the solidified volcanic mud the formation of which has been described. The angle of slope of these cones is much smaller than in the previous kind. It varies from 15° to 30°. Their internal character is the same as that of cinder cones. Their colour is much lighter. These cones eventually become impervious to water. The crevices become filled with the results of the decomposition of the materials contained in the tuffs. If such a cone becomes filled with water, a lake is formed like some in the north of Italy.

Lava cones.—The form of these depends upon the degree of liquidity of the lava from which they are formed. Viscid lavas form steep cones. Very fluid lavas give rise to cones with a gentle slope (Fig. 140). The gradual inclination of the sides of the lava cones at Hawaii also is due to the great liquidity of the lavas found there.

Compound cones are those partaking of the character of all or some of those described. They are built partly of scoriae, partly of tuffs, and in some parts of lava. The larger number of cones are of this compound nature. The variable materials of which the cone is built cause it to assume beautifully curved forms as the "angle of rest" of one material gives place to that of another. After a cone has reached a certain height it often happens that the force of the enclosed steam, to which eruptions are due, is insufficient to force the lava high enough for it to flow over the neck of the cone. In such cases the molten rock is forced through an opening made in the side of the cone. Often round such secondary necks new smaller cones are formed which constitute **parasitical cones.**

Distribution of volcanoes.—Volcanoes generally occur arranged along definite lines or curves. The formation of mountain ranges



Emery Walker Ltd. sc.

FIG. 142.

along belts of depression, or geo-synclines, which were marine regions in which thick deposits of sediments were laid down, will be mentioned in Chapter IX. There can be little doubt that the arrangement of volcanoes along lines is evidence of zones of weakness, or cracks, penetrating the earth's crust. In place of the thickening of the crust along the line of weakness, as in the formation of a mountain range of the ordinary type, there is here a fissure which penetrates to such deep-seated sources as to tap any molten material, which is forcibly ejected by the weight of the overlying rocks, and, reaching the surface, presents the phenomena of volcanic action. This *linear arrangement* is very marked along the coasts round the Pacific Ocean.

Many important active volcanoes, however, are found upon island festoons, such as those which extend from Java to Burma. The chief line which is followed by the volcanic activity of the Pacific can be traced, beginning from the most southerly limit of America, up the western coast of South America following the line of the Andes, through Central America, along the west coast of the northern half of America, by way of the Rocky Mountains, into the Aleutian Islands. Thence it passes by way of the Kurile Islands and Japan, all down the eastern coast of Asia, as far as the Malay Archipelago. Here the line divides, one branch passes in a north-westerly direction to Java and Sumatra, on to Barren Island; the other turns south-eastwards through New Guinea and passes on to New Zealand. Volcanic activity in south-western Asia (North Persia) follows the line of mountain axes from the borders of Baluchistan, while the volcanoes of East and North-East Africa are intimately related to the great fracture lines which make the Great Rift Valley from Nyasaland to the Red Sea.

There is a well-marked line in the Mediterranean Sea, which also roughly follows the axes of mountain ranges and along which Stromboli, Vesuvius, and Etna lie.

The line of volcanic activity is not so marked in the Atlantic Ocean. It can be traced from Jan Mayen, through several islands, Iceland, Azores, Ascension, St. Helena, to the West Indies.

Other forms of volcanic activity.—These phenomena can, in most cases, be traced to the same general causes as those which result in volcanoes. They represent, as a rule, the dying phases of volcanic activity and the heat emitted is drawn from deep-seated sources; they include **geysers** and **solfataras**.

Geysers.—The name " geyser " is derived from an Icelandic word, meaning a " roarer ". Geysers consist of fountains of hot water, which are intermittently active. Huge quantities of hot water and steam are forced up suddenly to a great height, and the eruption is followed by a period of rest.

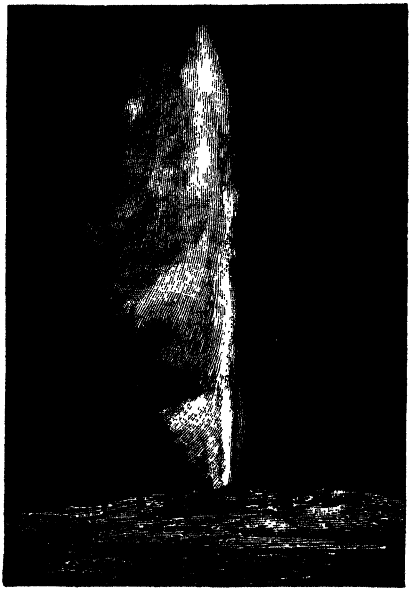


FIG. 143.—" Old Faithful " geyser in action.

In the case of "Old Faithful" geyser, in the Yellowstone Park of Wyoming (Fig. 143), this period of rest is nearly always of about 63 minutes duration. In this remarkable district of the United States a large number of geysers occur, scattered over a wide area; and among them are found, from place to place, pools of hot water, which though boiling in some parts are never projected into the air. It is usual to refer to these pools as *hot-springs*, keeping the expression " geyser " for those in an eruptive state of activity. It must be stated, however, that all hot-springs are not related to volcanoes, though most of them rise from considerable depths.

Geysers, as already suggested, are often seen in regions where volcanic activity has subsided to a feeble state, and they really only differ from volcanoes in the absence of any ejection of solid fragments and molten rock; they mark a declining stage in volcanic action, as a general rule, but it must not be forgotten that the water may be spring-water which has become heated by contact with hot rock or lava which owes its heat to the active phase of a volcanic eruption.

Though there are often so many geysers in the same neighbourhood, as in the Yellowstone Park, they are independent of one another, as was observed by Sir Archibald Geikie in this locality.

He remarked that " it seemed to make no difference in the height or tranquillity of one of the quietly boiling cauldrons, when an active projection of steam and water was going on from a neighbouring vent on the same gentle slope ".

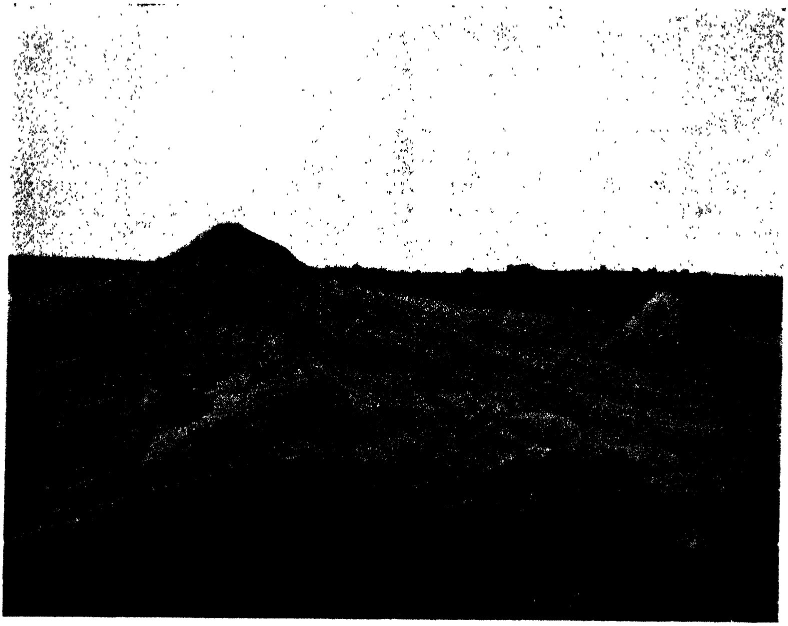


FIG. 144.—Typical mud volcano, Minbu, Burma. (With the permission of the Director, Geological Survey of India. Photo by E. H. Pascoe.)

The mode of formation of a geyser is well shown by an ingenious model designed by Bunsen. A column of water is heated in one part by a fire suitably situated. This heating gives rise to the development of a quantity of steam, which by its expansive force, at the moment the pressure becomes high enough, forces all the water above it into the air to a height depending upon the extent of such pressure.

Geysers are common in Iceland, the Yellowstone Park of the United States, New Zealand, and other places.

Solfataras.—If only steam and other gases are evolved from a vent in a region of volcanic activity, what is called a *fumarole* is formed, and if sulphur compounds are present in large quantities among such gases it is known as a **solfatara.** The Iranian volcanoes of Koh-i-Tafdan (Tuftan), Koh-i-Sultan, and Basman Koh have evidently settled down to the solfataric stage as has also Barren Island in the Bay of Bengal.

Volcanic activity and subsidence.—As evidence of the supposed connection between volcanic activity and movements of the earth's crust may be cited the well-known case of the activity of Vesuvius and the volcanoes in the Phlegraean fields and the elevations and subsidences undergone by the so-called "Temple of Serapis" on the shores of the Bay of Naples. Elevation above and subsidence below the sea have several times taken place in this district, as shown by the marks left upon the upright columns of the Temple still standing. Lyell, by a comparison of dates, showed that while Vesuvius was in eruption the Temple was subsiding and the volcanoes in the Phlegraean fields were quiescent. When, on the other hand, the latter were active, and particularly when Monte Nuovo was formed (1538), the Temple was slowly rising from the waves. Vesuvius has lately been in an active state, and the Temple is high and dry above the sea, but sinking.

Mud volcanoes.—The term **mud volcanoes** has been applied to those remarkable eruptions of liquid mud which occur with the discharge of organic, often inflammable, gases where vegetable or animal matter is decomposing. In the "passes" of the Mississippi delta curious bubbles of clay rise and burst and produce a good imitation of volcanic action. In Burma definite vents occur in the oil-fields region and in Ramri and Cheduba Island from which fluid mud is discharged with inflammable gases. In none of these cases is there any deep-seated connection with molten rocks, although these mud volcanoes lie along the lines of mountain axes. The heat is due partly to chemical action and partly to the great pressure exerted on folded strata from which water and gases are being squeezed out. In some rare cases perhaps mud volcanoes, or **salses,** are formed, where the geyser is active through beds of a clayey nature. When this is the case, instead of comparatively clear water being erupted, mud is given off, from which small cones are formed. They are said to be found in Iceland.

21. EARTHQUAKES

Their nature.—An earthquake is the result of a *sudden* disturbance in the earth's crust, resulting either from an explosive volcanic eruption or from some dislocation of the rock within a few miles of the surface. It is believed that the normal depth of origin is about 8 to 10 miles, but much greater depths are said to have been recorded: that of February 1, 1929, near Abbottabad, is estimated to have had its focus at a depth of nearly 100 miles. In the case of the Quetta earthquake of May 31, 1935, the so-called focus is believed to have been very shallow. Of only a small proportion of earthquakes has the cause been traced; in the majority of cases no satisfactory explanation has been offered and it seems likely that most earthquakes are due to forces not yet known. In those cases, however, where the nature of the disturbance appears most definite, it has been found to be either of **volcanic** origin or to be caused by sudden and deep-seated **dislocations**—often slipping movements—of great masses of rock.

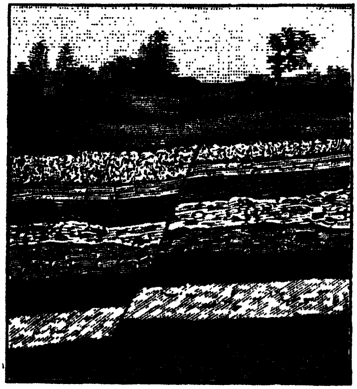


FIG. 145.—Section through a simple fault.

Dislocations of a similar, tectonic, nature sometimes take place gradually. Whether the movement is brought about suddenly, giving rise to an earthquake, or is accomplished by imperceptible degrees, evidence of the process remains in the form of bent and buckled strata, or in dislocations which represent planes of shearing in the rocks (Fig. 145). The most common type of dislocation is that known geologically as a **fault**, where layers, obviously once continuous, occur at different levels on the two sides of the separating surface. In those cases where the plane of shearing is almost horizontal and the strata appear to have been pushed over each other, the dislocation is referred to as a **thrust plane**.

Whatever its nature, the original impulse of an earthquake causes the particles in its neighbourhood to be displaced violently, and by virtue of the greater or less elasticity of the rock this displacement is transferred from one particle to the next in every direction. Crust movements are going on continually but are rarely detected except by delicate instruments. The slight ones, which represent most of those detected normally, are called **earth tremors.** Many of these are brought about by very slight disturbances of the crust, such as may be caused by great barometric changes, by high floods, by heavy landslips, by quivering of the rapidly rotating earth, by winds, and perhaps by the impact of waves on the seashore.

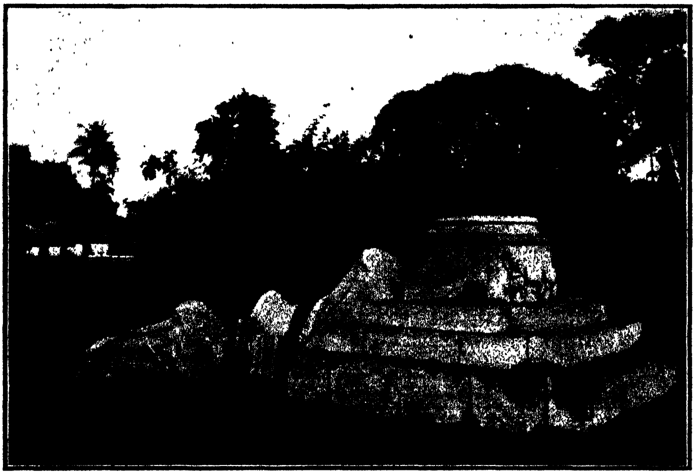


FIG. 146.—A fallen statue, after the Dhubri Earthquake, 1930. (With the permission of the Director, Geological Survey of India. Photo by C. S. Fox.)

Earthquakes are violent tremors.—The earthquake is propagated outwards from the place of disturbance, called the *focus* or *seismic centre,* in every direction. A position on the surface of the earth, vertically above the place of origin or seismic centre, is called the *epicentre,* but as the focus is seldom fixed, it has become usual to speak of the surface area estimated to be above the place of earthquake origin as the *epicentral region.* When the earthquake disturbance reaches the surface of the earth, it is felt as a rapid vibratory up-and-down wave-movement, and, according to the intensity and amplitude of the earthquake waves, anything which is unable to resist this motion falls. This is particularly the case with chimneys, steeples, obelisks, and so on. For this reason the village houses in Assam—where earthquake shocks are very common—are constructed of light and pliable materials like bamboo, wood and corrugated iron, which are able to stand the movements without fracture.

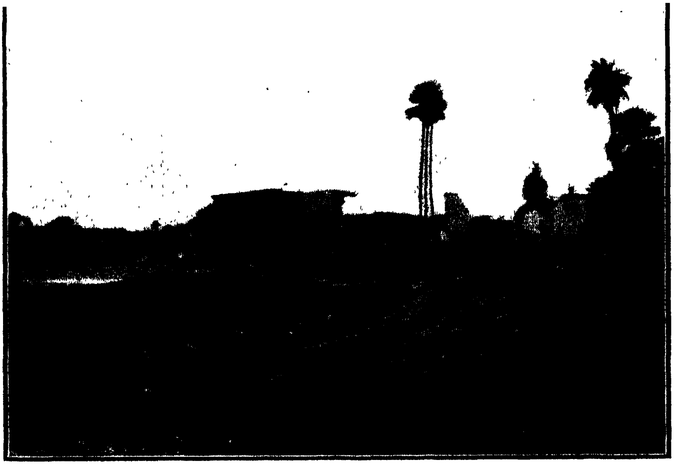


FIG. 147.—Earthquake damage due to "slumping" of the alluvial ground after the Bihar earthquake of January 1934. (With the permission of the Director, Geological Survey of India. Photo by J. B. Auden.)

The movement of the crust will scatter a pile of road metal like peas shaken in a pan; people have seen the surface move like the waves which cross a field of corn when gentle breezes blow over it; and Darwin observed that the trees dipped and recovered themselves, as the shock passed under them. The extent to which the ground is actually moved, *i.e.* the amplitude of the earthquake waves, even in destructive earthquakes, is surprisingly small, perhaps a foot at most and generally very much less—barely an inch or two. On soft alluvial ground in the epicentral region the movement may be complicated and produce cracks and discharge water as well as cause subsidence or "slumping", as Dr. J. A. Dunn termed it in the case of the Bihar earthquake of January 15, 1934, but on hard rock the vibrations are felt, but no cracks or permanent changes of the ground are usually noticeable, except perhaps landslips of hill sides. A movement of ¾ inch, occurring in a quarter of a second, is said to be sufficient to cause wholesale destruction.

Types of earthquakes.—Earthquakes of volcanic origin are often very violent at and near the crater of explosion, but do not usually make themselves felt at great distances, because the focus is practically at the surface and the energy is largely dissipated into the air. Earthquakes due to **dislocation**, on the other hand, usually occur at some depth below the surface, and as the energy is imparted to the rock crust they are felt over a greater area, and are much more destructive in effect. They are always followed by smaller quakes called *after-shocks*, which may succeed each other for days and weeks or longer. In dislocation quakes, as already mentioned, the origin or focus is rarely ascertained, but is thought to be a plane of slipping or sliding and may thus extend over a considerable area. This is believed to have been the case in several earthquakes—in fact the Assam earthquake of 1897 and the Bihar earthquake of 1934 are believed to have been caused by movements in more than one plane. It is thus clear that there can hardly be an epicentre, and so the epicentral region is not a point, or a line, but an area usually elongated in one direction which is often of considerable extent. The area in which the Bihar earthquake of 1934 was felt has been computed at nearly 2 million square miles, while the Quetta earthquake was only felt over an area of 100,000 square miles.

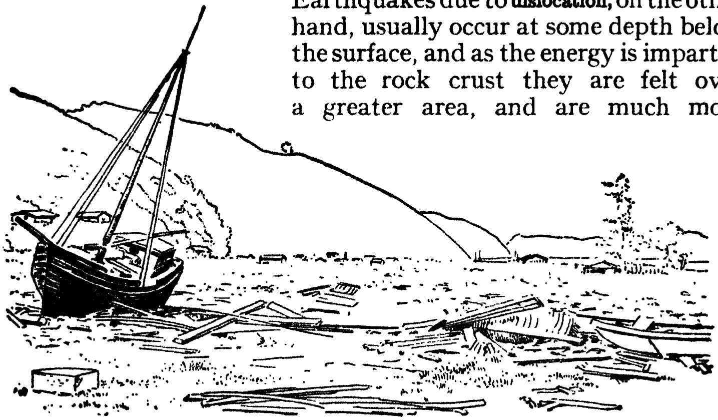


FIG. 148.—Effect of seismic water wave at Kamaishi, Japan, in 1896 (after E. R. Scidmore).

Water-waves. Any earthquake near or under the sea is accompanied by a sudden displacement of the bed of the sea. This usually gives rise to a wave in the ocean, which may travel, as in the case of the tremors previous to the main Krakatoa eruption, to distances of 4000 miles (to Aden) across the open sea. The waves caused by the explosion itself were detected as 9 inches high at Aden, 22 inches at Negapatam and of course of great height, 40 to 100 feet, on the adjacent coasts of Sumatra and Java. Ships happening to be in deep water are only subjected to an up-and-down movement. As the wave passes into shallow water it naturally increases in height and becomes fearfully destructive. Breaking, it changes the character of its motion. The water as a whole at first evidently retires as a negative super-wave and returning as a great super-wave is carried forward, and rushes on to the land with terrific violence, causing locally, as at Lisbon in 1755 and Messina in 1908, great damage and loss of life—by Krakatoa the destruction of the villages of Anger, Merak, Telok, Betong and others and drowning nearly their entire populations—over 32,500 people. A submarine earthquake, such as that of the Bay of Bengal on January 1, 1881, west of the Andaman Islands, the sensible effect of which is confined largely to sea waves, may be called a **sea-quake**.

Earthquake sound waves.—It is a common experience to hear rumbling sounds, like distant gun-fire or the passing of a heavy train a short way off, during, just before, or immediately after a strong earthquake tremor. The noise appears to be caused by the vibrations of the ground surface being communicated to the air, but in some cases, as for example the "Barisal guns", this explanation may not be sufficient, as these reports are heard when no earthquake shock is felt by the observer. The phenomenon has not been fully investigated.

Indian earthquakes.—Although the Assam earthquake of 1897, when about 1600 lives were lost, was perhaps the most violent earthquake of history, it was not so destructive or so disastrous as the Kangra earthquake of 1905, when 20,000 lives were lost; but so far as destruction of property, of life and changes of landscape are concerned, the most tragic was the Quetta earthquake of 1935, when 25,000 lives were lost in the dead of night and the town was practically destroyed. The histories of these earthquakes have been written by officers of the Geological Survey of India and are published by the Government of India, so that students may procure copies and read details for themselves.

The following details of important Indian earthquakes are given in an appendix to Mr. W. D. West's Presidential Address (Section of Geology and Geography)—"Earthquakes in India"—at the 24th Indian Science Congress, held at Hyderabad in January 1937.

IMPORTANT INDIAN EARTHQUAKES[1]

1505. July 6. A very severe earthquake, felt from the United Provinces to Persia, causing great damage and loss of life around Kabul. Felt at Agra and Delhi.

1668. May. Delta of the Indus. Caused great damage.

1720. July 15. Delhi. Damage was done to the walls of the fort and to many houses, cracks developed in the ground, and many lives were lost. After-shocks were felt in Delhi for some weeks. The position of the epicentre is unknown.

1737. October 11. Calcutta. Many houses thrown down, and the spire of the English church sank into the ground. Many ships were lost in the accompanying hurricane, and great loss of life occurred.

1762. April 2. Bengal and Burma. Felt most severely along the N.E. coast of the Bay of Bengal. Chittagong suffered severely, fissures opening in the ground, with fountains of water and sand.

1803. September 1. United Provinces. Very severe at Muttra, many pukka buildings and the principal mosques being destroyed. Severe in the Simla and Kumaon hills. Damaged the Qutb Minar at Delhi. Felt at Calcutta.

1819. June 16. Cutch. Felt over practically the whole of India, including Calcutta, and was one of the greatest of Indian earthquakes. 2000 lives lost at Bhooj alone. The great mosque of Sultan Ahmed at Ahmedabad destroyed after standing 450 years. An elevation of the ground for 80 miles on the north side of a fault running E.-W. temporarily dammed up a branch of the Indus. The Runn of Cutch flooded on the downthrow side of the fault.

1827. September. Lahore. Fort Kolitaran, near the city, destroyed, and 1000 said to have perished.

1828. June 6. Kashmir. Very severe. 1000 reported killed. Fissures opened in the city. Followed by a great number of after-shocks for some months.

1833. August 26. Bihar and Nepal. Felt over much the same area as the 1934 earthquake, though possibly not quite as severe.

1839. March 23. Burma. A very severe earthquake, felt over the whole of Burma, but most strongly around Mandalay. Amarapoora and Ava destroyed, and the stupendous temple of Mingon overthrown.

1842. February 19. N.W. India. Felt from Kabul to Delhi, the epicentre probably near Jellalabad. Jellalabad and Peshawar severely damaged.

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[1] This list is based mainly on T. Oldham's catalogue.

1843. April 1. Deccan. The only earthquake in peninsular India known to have caused much damage. Epicentre near Bellary.

1852. January 24. Upper Sind. Fort of Kahan ruined, and 350 killed. Severe but local.

1858. August 24. Burma. Very severe, especially around Thayetmyo and Prome. Felt in Bengal. Sympathetic shocks in Madras and Bombay.

1869. January 10. Assam (Cachar). Felt over an area of 250,000 square miles, the epicentre being on the north-east side of the Shillong plateau. Earth fissures and sand craters very abundant, and their origin discussed for the first time by T. Oldham.[1]

1881. December 31. Bay of Bengal. Felt over an area of 2,000,000 square miles, mostly sea.[2]

1885. May 30. Kashmir. Felt over an area of 110,000 square miles, the epicentre being a few miles west of Srinagar. About 3000 lives lost.[3]

1885. July 14. Bengal. Felt over an area of 230,000 square miles. Epicentre north-west of Dacca.[4]

1892. December 20. Chaman, Baluchistan. Associated with a fault running N.N.E. along the western side of the hills. As a result of the earthquake the country west of the fault subsided a foot, and moved bodily 2½ feet southwards.[5]

1897. June 12. Assam. Probably the greatest earthquake that has occurred anywhere during historic times. Felt over an area of 1,750,000 square miles, with the epicentre in the Shillong plateau. Exhaustively studied by R. D. Oldham, who suggested a complicated origin for it. Destruction of stone buildings almost universal in Shillong, Goalpara, Gauhati, Nowgong and Sylhet. Calcutta seriously affected. About 1600 lives lost. Followed by a great train of after-shocks.[6]

1905. April 4. Kangra. Felt over an area of 1,625,000 square miles. 20,000 lives lost. Kangra, Dharmsala and neighbouring places completely ruined. Origin attributed by C. S. Middlemiss to movement along one of the Himalayan reversed faults, at considerable depth.[7]

1909. October 21. Baluchistan (Kachhi). Epicentre located on the alluvial plain; very elongated, aligned N.W.-S.E. 231 lives lost.[8]

1912. May 23. Burma. Felt over an area of 375,000 square miles.

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[1] *Mem. Geol. Surv. Ind.*, XIX, Pt. I (1882).

[2] R. D. Oldham, *Rec. Geol. Surv. Ind.*, XVII, p. 47 (1884).

[3] E. J. Jones, *op. cit.*, XVIII, p. 221 (1885).

[4] C. S. Middlemiss, *op. cit.*, XVIII, p. 200 (1885).

[5] C. L. Griesbach, *op. cit.*, XXVI, p. 57 (1893).

[6] *Mem. Geol. Surv. Ind.*, XXIX (1900); and *op. cit.*, XLVI, Pt. 2 (1926).

[7] *Rec. Geol. Surv. Ind.*, XXXII, p. 258 (1905); and *Mem. Geol. Surv. Ind.*, XXXVIII (1910).

[8] A. M. Heron, *Rec. Geol. Surv. Ind.*, XLI, p. 22 (1911).

Epicentre located close to the Kyaukkyan fault on the Shan plateau north-east of Mandalay.[1]

1918. July 8. Srimangal (Assam). Many tea estates ruined. Epicentre 3½ miles south of Srimangal on an alluvial tract. Felt over an area of about 800,000 square miles. Sympathetic shocks off the Madras and Arakan coast. Re-levelling suggests that the earthquake was due to subsidence along the southern side of a normal fault cutting the rocks below the alluvium.[2]

1929. February 1. North-west Himalaya. Epicentre about 25 miles north-west of Abbottabad. Of interest as being a deep focus earthquake, the depth calculated to be 160 kms.[3]

1930. May 5. Pegu. Felt over a land area of 220,000 square miles. About 550 lives lost. The epicentre a long elongated tract S.S.E. of Pegu, aligned N.-S. Origin thought by J. Coggin Brown to be connected with the boundary faults of the Shan plateau, but perhaps intensified by increasing strains due to the growth of land into the Gulf of Martaban.[4]

1930. July 3. Dhubri, Assam. Epicentre at north-western end of the Garo Hills. Felt over an area of about 350,000 square miles. Origin thought by E. R. Gee to be mainly due to movement along a line of tectonic weakness at the margin of the Assam range, accentuated by the disturbance of isostatic equilibrium consequent upon the rapid denudation of the range.[5]

1931. August 27. Mach, Baluchistan. Epicentre located down the Bolan pass and along the junction of the hills with the Kachhi plain. Felt over an area of 370,000 square miles. About 200 lives lost.[6]

1934. January 15. North Bihar. One of the most severe in Indian history. Felt over an area of 1,900,000 square miles. At least 10,000 lives lost. Epicentre occupied a belt aligned W.N.W.-E.S.E. and running for some 80 miles from east to Motihari through Sitamarhi to Madhubani. Origin attributed by D. N. Wadia, J. A. Dunn, J. B. Auden and A. M. N. Ghosh to movement along a fault or series of faults below the alluvium.[7]

1935. May 31. Quetta. Epicentre a narrow tract running 68 miles S.S.W. from Quetta through Mastung. Felt over an area of only 100,000 square miles, but very severe at the epicentre. About 25,000 lives lost, and great material damage in Quetta. Exact origin unknown, but the focus was probably shallow.[8]

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[1] J. C. Brown, *Mem. Geol. Surv. Ind.*, XLII, Pt. 1 (1914).

[2] Murray Stuart, *Rec. Geol. Surv. Ind.*, XLIX (1918); and *Mem. Geol. Surv. Ind.*, XLVI, Pt. 1 (1920).

[3] A. L. Coulson, *Rec. Geol. Surv. Ind.*, LXII, p. 279 (1929); and *op. cit.* LXIII, p. 434 (1930).

[4] J. C. Brown and P. Leicester, *op. cit.*, LXV, p. 221 (1931).

[5] *Mem. Geol. Surv. Ind.*, LXV, Pt. 1 (1934).

[6] W. D. West, *op. cit.*, LXVII, Pt. 1 (1934).

[7] *Rec. Geol. Surv. Ind.*, LXVIII, p. 177 (1934).

[8] W. D. West, *op. cit.*, LXIX, p. 203 (1935).

The Messina-Reggio earthquake.—The most disastrous earthquake recorded in Europe occurred on December 28, 1908, in the district of Sicily and South Italy, when the towns of Reggio and Messina were almost completely destroyed. The disaster was preceded by torrential rain. The shock lasted 37 seconds, and in that short time wrecked the whole province of Calabria and caused the death of thousands of people. The chief centre of the disturbance seems to have been beneath the sea and the cause the sudden movement along the bottom of the Strait of Messina. The earthquake was followed by a destructive sea-wave, which rose to a height of 25 feet, sweeping over the coasts on both sides of the strait. This sea-wave, and probably the earthquake itself, was evidently caused by a simultane-

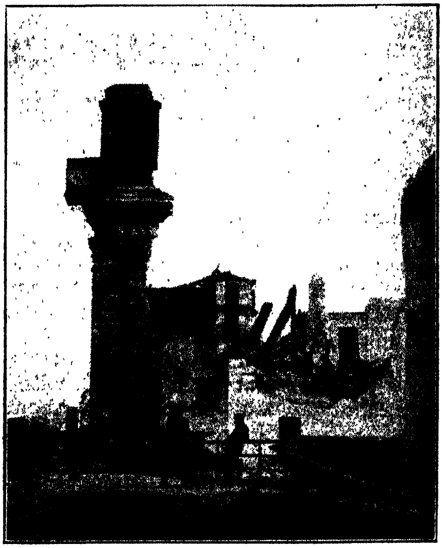

FIG. 149.—Messina-Reggio earthquake of December 28, 1908. A wrecked house on Via Porta Imperiale, Messina. The clock on the corner post indicates the time of occurrence of the earthquake, 5.20 a.m. (From the *Bulletin of the Imperial Earthquake Investigation Committee, Tokyo,* November 1909.)

ous sinking of the bottom of the strait through a depth of 3 to 6 feet, as was proved by soundings.*

The whole character of this part of Italy and Sicily has been changed ; the level of the sea-shore has been raised, and the interior now presents a twisted appearance with huge fissures in the surface. After-shocks continued at intervals for some weeks.

Some connection between volcanic activity and this earthquake is suggested by the fact that Stromboli, quiescent before the disturbance at Messina, suffered an eruption some six days afterwards.

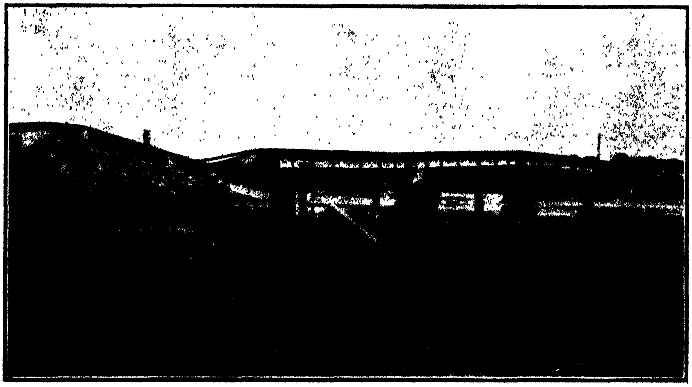

FIG. 150. Damage to the Sitamari railway bridge as a result of the Bihar Earthquake of January, 1934. (With the permission of the Director, Geological Survey of India. Photo by A. M. Ghosh.)

San Francisco earthquakes.—The peninsula of San Francisco has provided a good example of a close association of earthquake activity and the readjustment of rock masses. More than 200 earthquakes of varying intensity have occurred here since 1850, and the presence of several lines of faults, running across country in a north-westerly direction towards the sea, shows that the underlying rocks have been dislocated to a very great extent. The origin of Californian earthquakes in general, has, like most other great earthquakes, been found to be deep seated. In April, 1906, an earthquake lasting just over a minute wrecked a great part of the city, and a terrible fire which broke out immediately afterwards completed its destruction. Careful measurements have shown that the coast of California, from north to south, is slightly and measurably longer than it was 50 years ago. Indeed, the belief is growing that expansion of the upper

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* See *Nature*, vol. 79, p. 288 (1909) ; also *American Jour. Sci.*, IV series, vol. xxvii, p. 221 (1909), where, according to F. A. Perret, the loss of life and property was enormous owing to the " rubble " construction of the buildings and the early hour (5.20 a.m.) of the shock. Properly constructed houses in Calabria withstood the shock. The embankment at Messina appears to have collapsed by sliding down into the deep water of the harbour.

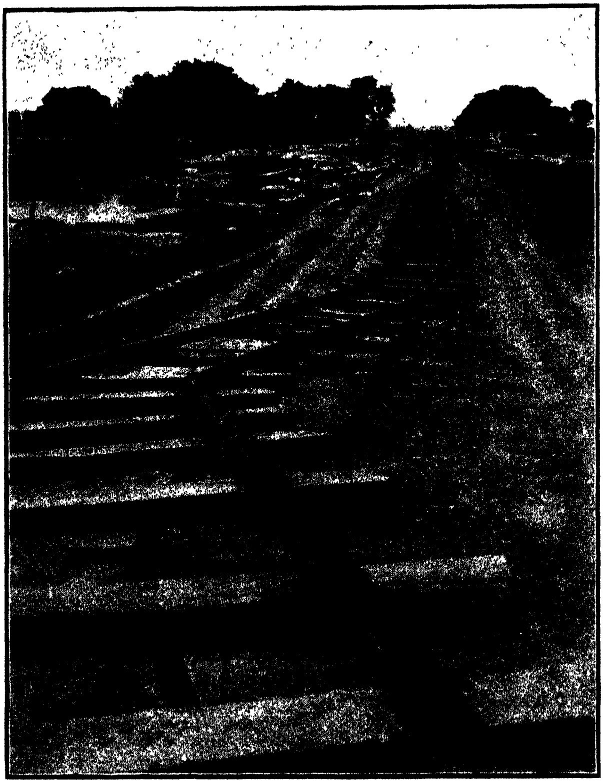

FIG. 151.—Earthquake damage to railroad track in the alluvial area of Rangpur, Bengal, after the Dhubri earthquake of 1931. (With the permission of the Director, Geological Survey of India. Photo by E. R. Gee.)

strata is the usual cause of the break which accompanies a " dislocated quake ".

Japanese earthquakes.—Although India has lately been visited by frequent earthquakes, perhaps Japan, above all other countries, has had more than her share of such disasters—the great earthquake of Mino Owari in 1891, Kwanto in 1923, Tajima in 1925 and Oku Tango in 1927—almost prostrated the commerce of Japan by the destruction caused to Tokyo and Yokohama and other great business centres of that country. The people have been forced to take notice of this form of natural calamity and in consequence Japan leads the world in her studies of seismological effects. The student of seismology must make himself acquainted with the publications of the Japanese seismologists to realise how carefully the matter is being watched, and how much valuable data has been accumulated. Earthquake-proof buildings, so far as such structures can be proof against all but the greatest shocks, have long been adopted in Japan and have proved their value both in their own country and in those where a similar prudence has been followed.

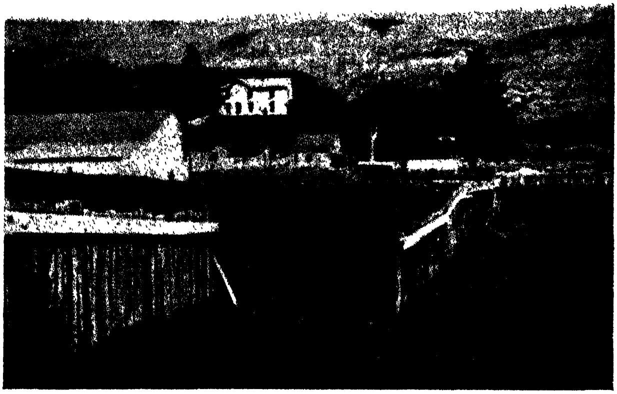

FIG. 152.—Fence parted by horizontal movement along the fault, San Francisco earthquake of April 1906. (From *Bulletin* 324, *U.S. Geol. Survey.*)

Distribution of earthquakes.—Slight earth tremors are occasionally felt almost everywhere; but the more noticeable disturbances which are included under the term earthquakes are much more frequent along the lines followed by recent volcanoes or the newer mountain ranges of the world—the Himalayas and adjacent mountains of Assam, Burma, and Baluchistan ; the mountains of Persia and Asia Minor ; the coastal ranges of the Pacific Ocean ; etc.

Count de Montessus de Ballore, a well-known authority on earthquakes, pointed out that, as a general case, earthquakes are most numerous where variations of topographical relief are greatest ; and that unstable regions are associated with the great lines of tectonic folding of the earth's crust. As examples of the truth of this generalisation, Major Dutton, another early seismologist, stated that the profound depth of the ocean (nearly 4000 fathoms) just off the eastern part of the Aleutian Chain is " one of the greatest breeding grounds of world shakers " ;* also, *à propos* of the great frequency of earthquakes in the West Indies, that the sea bottom in the vicinity of the Great Antilles is one of the most rugged and highly diversified in its profile of any part of the earth. Again, most Japanese earthquakes " originate in that great slope of the sea bottom which leads down to the Tuscarora Deep " (Figs. 95 and 96). However, these are all cases involving structural factors which are of far deeper significance than merely those of relative ocean depths, and involve questions which refer to the actual origin of earthquakes and volcanoes—a problem that remains unsolved.

Very few earthquakes in the western or northern Pacific are believed to be of volcanic origin, but volcanic activity is not absent in these regions, and Californian earthquakes, judged from the estimated depth of their place of origin, also appear to be caused by dislocation. The earthquakes of Central America and South Mexico, on the other hand, are obviously associated with volcanoes (which are more numerous and closely adjacent here than anywhere else in the world) and are thought to be of shallow origin. In the region of the Andes both volcanic and dislocation quakes are evidently abundant and intermingled. On the coast of Chile and near the Andes, earthquakes are very common. When they occur in the sea bottom they give rise to destructive sea-waves. Although Major Dutton states that the expression " the great fiery circle ", sometimes used for the line of volcanoes which surrounds the Pacific, has no existence in fact, since the earthquake regions round this ocean are so widely separated by areas of repose, it nevertheless

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* Dutton's " Earthquakes in the Light of the New Seismology " (Murray).

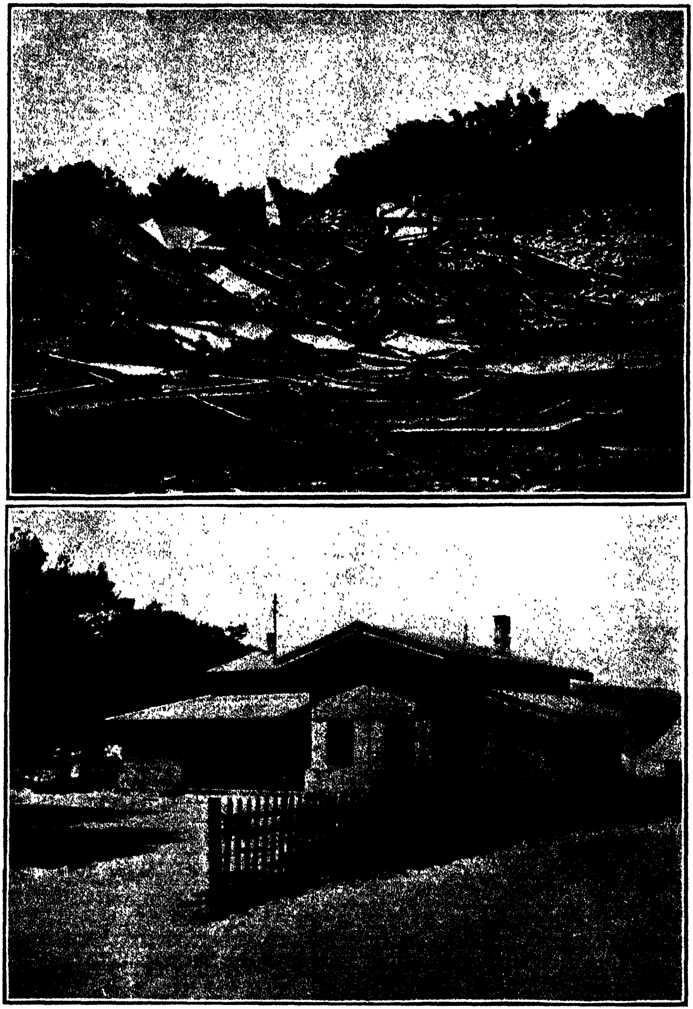

FIG. 153.—Photographs taken of two buildings on opposite sides of a road in Quetta after the earthquake of 1935. The upper view shows a badly constructed old building utterly demolished. The lower picture shows a modern well-built bungalow undamaged. (With the permission of the Director, Geological Survey of India. Photo by W. D. West.)

conveys a good idea of the zone of tectonic weakness along this part of the earth's crust.

All the great earthquake regions follow mountain ranges which border the oceans or lie along island arcs or festoons. They also include the mountain systems of southern Europe bordering on the north of the Mediterranean, including the Italian and Balkan peninsulas, and extending eastward into southern Asia through Persia and Turkestan to the Hindu Kush and the Pamirs and so to the Assam region via the Himalayas.

Earthquake intensities.—The late Mr. R. D. Oldham, who was perhaps the greatest seismologist in his day, adopted the following scale of earthquake intensities :

No. 1 being the area of the epicentral region within the first isoseist in which there is generally complete destruction of stone and brick buildings ;

No. 2 enclosed by the second isoseist in which there is serious damage to masonry and brick buildings amounting to destruction ;

No. 3 isoseist marks the limit of strong shocks which are violent enough to damage nearly all brick buildings ;

No. 4 isoseist encloses the area of the felt shock where loose objects are disturbed but few buildings damaged ;

No. 5 isoseist outlines the zone in which the shock is noticed but is not severe enough to cause any damage ;

No. 6 isoseist demarcates the limits within which the shock is only noticed by people sitting or lying down or otherwise favourably placed ; and

No. 7 isoseist is the boundary where the shock is only noticed by sensitive people or recorded on a seismograph, but otherwise not noticed.

This is a good rough scale for practical purposes, but the most commonly accepted scale is that known as the Rossi-Forel. In Italy the Mercalli scale is in use and in Japan the excellent scale introduced by Omori and called by his name.

An isoseist is the line of equal intensity between two zones of earthquake intensities—thus, No. 3 isoseist of Oldham's scale corresponds with V on the Omori scale and with VIII on the Mercalli and Rossi-Forel scales.

EPICENTRAL REGION OF GREATEST INTENSITY

Oldham's Scale (India)	Mercalli Scale (Italy)	Rossi-Forel Scale (General)	Omori Scale (Japan)	Acceleration in millimetres per second per second
No. 1 isoseist	No. X	No. X	No. VII	greater than 4000
No. 2 ,,	No. IX	No. IX	No. VI	4000
No. 3 ,,	No. VIII	No. VIII	No. V	2500
No. 4 ,,	Nos. VII & VI	Nos. VII & VI	No. IV	2000
No. 5 ,,	No. V & IV	Nos. V & IV	No. III	1200
No. 6 ,,	Nos. III & II	Nos. III & II	No. II	900
No. 7 ,,	No. I	No. I	No. I	300

Seismographs.—Information of the manner in which earthquake shocks are transmitted has been gained chiefly from instruments which record the movements of the ground. Such instruments are known as seismographs. In principle a **seismograph** is a pen in contact with a sheet of paper moved by clockwork. The pen is so suspended that it remains as nearly as possible at rest, although its supports may be in motion. The paper is connected with the earth, and shares all movements of the ground, so that the pen traces a line which is straight when the earth is undisturbed, but becomes wavy when the earth is shaken. A line or diagram of this kind is called a **seismogram** (Figs. 154, 156 and 157).

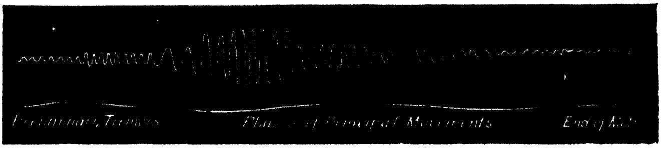

FIG. 154.—Typical diagram of a long-distance seismogram. (Omori.)

Horizontal pendulums.—Many very complicated seismographs have been devised, with the objects of obtaining as perfect a " steady point " as possible, of procuring records of motion in any direction, and of magnifying the motion so that all its details may be studied closely. Some of the most important results have been obtained with various forms of horizontal pendulum. In its simplest form, a *horizontal pendulum* is a rigid rod pivoted at one end in such a manner that it can only move in a horizontal plane. In principle it is similar to an ordinary field gate, being supported at one end on pivots or hinges, and free at the other end. If a pendulum of this kind has at its free end a stiff bristle or light pen fixed vertically to it, while its lower end touches a piece of smoked paper, then it is easy to understand that if the surface of the ground shakes to and fro horizontally, owing to earthquake vibrations, the paper is carried to and fro under the pen fixed to the horizontal pendulum and a record of the movement is thus obtained.

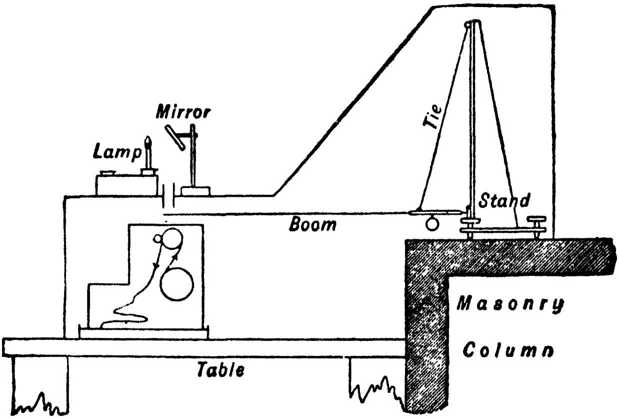

FIG. 155.—Type of horizontal pendulum devised by Prof. Milne, and adopted by the Seismological Investigation Committee of the British Association.

Although many new patterns of seismographs are now available the horizontal pendulum originally devised by Prof. Milne to record earthquakes, diurnal waves, tremors and other small earth movements as shown in Fig. 155, is still very useful.* The end of the pendulum near the stand has upon it a vertical point resting in a small agate cup. The rod is supported horizontally by means of the tie of silk thread or quartz fibre shown in the figure. The outer end of the boom of the pendulum carries a small aluminium plate in which there is a slit. This is free to swing to the right or left over a slit in the lid of a box in which clockwork drives a band of photographic paper. Light from a lamp is reflected by a mirror to the two crossed slits, and reaches the paper at a luminous point, which in consequence of the motion of the paper becomes a line on the photographic record. When there are no earth movements, the record is a straight line, but when earthquake waves or tremors disturb the place where the instrument is fixed, the line becomes broken (Fig. 156).

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* See *Nature*, Jan. 20, 1898.

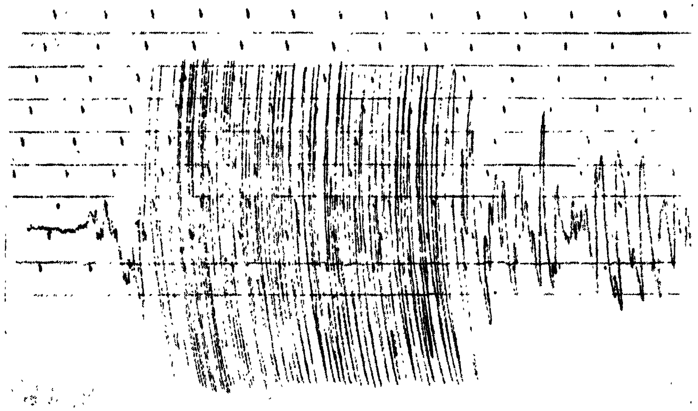

FIG. 156.—Seismograph record of the great Quetta earthquake, obtained at the Agra Observatory on May 31, 1935. The preliminary tremors appeared at 03 hrs. 5 mins. 15 secs. I.S.T. and the secondary waves followed after 1 min. 45 secs. The destructive long waves which appeared at 03 hrs. 8 mins. 10 secs. I.S.T. continued for 7 mins.

Other important types of horizontal seismographs are those devised by Dr. E. von Rebeur Paschwitz, Dr. Omori, Dr. E. Wiechert, and Prince Boris Galitzin.

Earthquake waves.—Mr. R. D. Oldham first recognised that the shock of an earthquake is transmitted from the seismic centre or place of origin to distant points on the earth's surface by three different classes of earth waves. The **Primary** or (push) P. waves which travel fastest and arrive first at a seismograph outside the epicentral regions are of a compressional (to and fro) or **longitudinal**

type and are transmitted through fluids and solids. The **Secondary** or (shake) S. waves are next fastest and are distortional or **transverse** vibrations, *i.e.* oscillating perpendicularly to the direction of travel, and can only be transmitted by solids but not by liquids. Both these types of waves, the P. and S., travel through the *interior* of the earth, in nearly straight lines. The waves of the third kind, known as the **long** or L. waves, travel like the waves of the sea, *i.e.* with a rotary movement in a vertical plane, in the direction of propagation, which is along the earth's surface, approximately along the arcs of great circles, from the centre of disturbance to distant points. They are slower than the S. waves but have longer wavelengths and amplitudes and it is through them—the L. waves—that the greatest damage by an earthquake is done. They are not felt in deep mines.

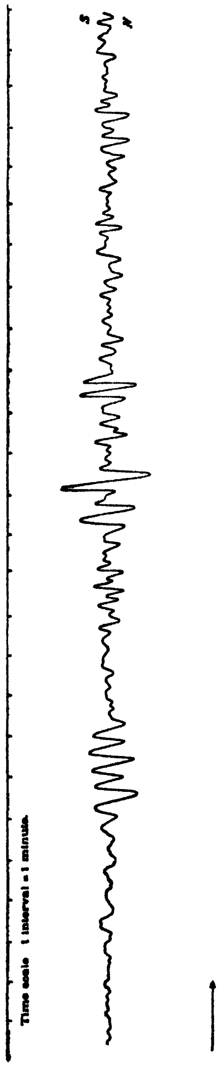

FIG. 157.—Long-distance seismogram of the Messina-Reggio earthquake of December 28, 1908, obtained by Dr. F. Omori in Tokyo. The preliminary tremors commenced at 1 h. 32 m. 8 s. p.m., by 1st Normal Japan time, which is 8 hrs. ahead of Central Europe time. (Compare Fig. 154.) The illustration shows the principal portion of the N.-S. movement magnified 9 times. The arrow shows that the record begins on the left. (From the *Bulletin of the Imperial Earthquake Committee, Tokyo*, November, 1909.)

The location of earthquakes.—Though all the vibrations or waves set up in the earth's crust and core by a particular earthquake disturbance start at the same instant from their place of origin, the P. and S. waves do not travel with the same velocities. An important fact which has emerged from Prof. Milne's observations is that on every seismogram a number of small movements or tremors due to the P. and then the S. waves are seen before the vibrations due to the long L. waves, and the duration of these preliminary tremors increases between each other and the long waves according to the distance of the seismograph from the place of origin of the earthquake. It is thus possible, knowing the approximate velocities of the P. and S. waves, to estimate the distance of the place of origin from a given station by observing the duration of the preliminary tremors between the P. and S. waves and between the S. and L. waves as recorded by a seismograph.

Thus by ascertaining the duration between the P. and S. wave arrivals and between the P. and L. wave arrivals, assuming chord directions for the P. and S. waves and great circles for the L. waves, the distances to the focus and to the epicentral region may be established as was done by Dr. Omori at Tokyo for the Messina-Reggio earthquake of December 28, 1908. He found that the difference in time between the arrivals of the P. and L. waves at Tokyo was 11 min. 39 sec. and that the time of travel of the L. wave was 23 min. 30 sec., and calculated evidently with an L. velocity of nearly 7 kilometres per second and arcual distance of 9930 kilometres as against 9900 kilometres on the great circle joining Tokyo with Messina. It is seen that the rate of travel of the L. waves was clearly far more than the average usually now taken. Also a small calculation will show that the speed assumed or attained by the P. waves, even on a chord direction, must have approached 10 kilometres per second.

In the case of the Dhubri earthquake of July 3, 1930, Mr. E. R. Gee estimated the rates of travel of the various waves as below :

Place (Dhubri as centre)	Arcual distance	Rate in kilometres per second		
		P.	S.	L.
Alipore (Calcutta) - -	7·54	7·2	?	4·0
Dehra Dun - - -	14·63	7·3	4·4	3·4
Colaba (Bombay) - -	21·50	8·4	4·6	3·6
Colombo - - -	24·46	9·1	5·0	3·5

The long waves appear to travel—in great circles along the earth's crust—at a fairly uniform speed of 3·6 kilometres, say 2 miles, per second. It is therefore possible, from observations of the respective times of arrival of the long waves at three or more widely separated stations, to determine the position of the epicentral region of an earthquake. Methods have also recently become possible of finding this point from the record of a single seismograph.

The speed of the P. and S. waves travelling through the inner shells and the core of the earth are now known to be roughly as below:

Zone of	At a depth of	P. waves	S. waves
Granite shell	10 Km.	from 5·5 Km. per sec.	from 3·3 Km. per sec.
Basalt ,,	below 10 ,,	to 6·3 ,,	to 3·7 ,,
Dunite ,,	,, 40 ,,	to 7·8 ,,	to 4·4 ,,
Inner ,,	,, 1200 ,,	to 13·0 ,,	to 7·2 ,,
Core - -	,, 2900 ,,	to 8·5 ,,	nil

From such data the elasticity of the earth has been calculated, and it has been computed that the earth as a whole must be at least as rigid as if it were composed wholly of steel. From the behaviour of the various types of P. and S. earthquake waves it has been concluded that the earth has a central molten core of nickel iron, which is covered by an inner layer of metallic sulphides or pallasite. This is thought to be covered by a middle layer of peridotite or eclogite, and this in turn is covered by the outer shell or rocky crust (lithosphere).

EXERCISES ON CHAPTER VIII

1. Give a full account of the phenomena (terrestrial and marine) produced by earthquakes.

2. What is a volcano? Write a short description of the usual form and structure of one.

3. What are the principal products given out by an active volcano? Describe the structure of a typical volcanic cone.

4. Describe the effects of an earthquake near a sea coast. What regions of the globe are specially subject to earthquakes?

5. What is a volcano? In what ways does volcanic energy manifest itself? Describe, and show by a map, the principal zones of volcanic action.

6. Describe accurately a volcano, both when quiet and when active. Discuss the distribution of volcanoes on the earth.

7. Give a brief account of (*a*) the gaseous, (*b*) the liquid, (*c*) the solid materials ejected from volcanoes.

8. What is lava? Describe some of the commonest types.

9. What differences have been noticed in the behaviour of the true volcanoes of the Pacific and the mud volcanoes of the Burmese oil-fields and the Arakan coast?

10. Give an account of any particular volcanic eruption.

11. Write a short essay on the geographical distribution of volcanoes.

12. What is a geological fault? In what manner may such a fault have been formed?

13. What are the known causes of earthquakes? Give two examples of each kind you mention.

14. Explain the terms *isoseist, seismic centre, focus, epicentre, epicentral region, seismograph* and *seismogram.*

15. What is the general principle on which a seismograph is constructed?

16. Describe a typical " long distance seismogram " and explain its most important features.

17. Explain generally how (*a*) the distance, (*b*) the position of an earthquake may be determined from the records of seismographs.

18. What light has earthquake study thrown on the condition of the earth's interior?

19. Write a short essay on the geographical distribution of earthquakes.

20. How are the chief active volcanoes of the world distributed?
How would you recognise a region of volcanic formation if you were travelling through it?

21. How does volcanic action affect the earth's crust?

CHAPTER IX

THE ORIGIN OF ROCK MASSES

22. THE FORMATION OF STRATIFIED ROCKS

1. Examination of chalk and limestone.—Smash pieces of Nummulitic * limestone and look carefully for shells or other animal remains among the pieces. Brush a piece of natural chalk (*not* blackboard chalk) with a stiff tooth brush in water, and with a microscope or strong magnifying glass examine the sediment for small shells.

Pour a drop of dilute hydrochloric acid, or strong vinegar, on the chalk, and describe the result.

2. The effect of pressure on mud.—Collect some stiff mud from the bank or dry bed of a pond or river. Put it in a box and cover it with a board just small enough to go into the box. Put heavy weights on the board, and leave the whole arrangement until the water pressed out has had time to dry up. Examine the dried and compressed mud and compare it with shale.

Test a little shale with acid.

3. The process of infiltration.—(*a*) Put some sand in a dish. Cover it with lime-water. In another dish place some similar sand covered with water. Leave both dishes exposed until the water in each has dried up. Compare the contents of the dishes. Can you suggest any method by which sandstones are formed in nature?

(*b*) Put a small piece of red sandstone in a test tube. Cover it with strong hydrochloric acid, and then put the tube in boiling water until the acid has dissolved the oxide of iron which holds the grains of the sandstone together. Pour off the reddened acid and wash the remaining sand with water. What is the colour of the loose grains of sand?

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* The so-called Sylhet limestone from the Khasi hills, Assam, or the Eocene limestones of the Punjab Salt Range and elsewhere in India, will be suitable for these tests.

4. Stratified rocks. (*Outdoor work.*)—Whenever opportunity occurs examine the exposures of rock in quarries, railway cuttings, etc., and write a description of any rocks arranged in layers, noting the " dip " or angle which the layer makes with the horizontal, and the point of the compass toward which the layer slopes.

The formation of stratified rocks.—The action of rain, rivers, and glaciers has been shown in Chapter VII to result in the deposition of rock fragments in the form of fine silt or clay on the bed of the sea, or of lakes. At the time of their deposition almost all such sediments tend to settle down in layers, or **strata,** which are roughly parallel and horizontal. That they are not strictly so is apparent from the most cursory examination. Nor can it be expected that they will be strictly parallel when the conditions of deposition are considered. Imagine a river carrying a quantity of such rock detritus, consisting of mud, sand and gravel, into the quiet waters of a lake ; it is clear that the heaviest gravel must be deposited first, and be succeeded by the sand and mud in order, forming a roughly parallel arrangement. Whenever the area over which deposition is taking place is larger, the volume of suspended material greater, and the process of deposition slower, the approach to parallelism is more marked (Fig. 159).

In the absence of any disturbance of the strata, those beds which lie beneath must have been deposited before, or are older than, beds occurring above. In this way the geologist arrives at conclusions as to the relative ages of strata.

Main divisions of stratified rocks.—Fig. 158A is a table of the principal Indian and European groups of stratified rocks, in the order of their deposition (the oldest at the bottom and the youngest at the top), since the beginning of *Geological Time* on a vertical scale of millions of years. The **Geological Record,** Fig. 158B, as used in Britain, gives a comparison of the divisions into which the time scale has been subdivided. Each division possesses characters by which rocks, laid down during the same period of geological time, can be recognised in whatever part of the world they may occur. As is natural, the same name is used to denote both the rocks themselves and the interval of time during which they were being deposited. Thus, by the Dravidian *Era* is meant the lapse of time during which the formations of the Dravidian *Group* was laid; by the Lower Gondwana *Period* is meant the interval of time during which rocks of the great coal-bearing strata of India—the Lower Gondwana *System*—were being deposited. On Fig. 158A are represented the main **classes** of strata, corresponding to the great **eras** of time:

I, the most ancient of all, the *Archaean*;

II, the next, also unfossiliferous, known as the *Purana*, which includes the Algonkian of America and the pre-Cambrian beds of Britain;

III, the *Dravidian*, which almost corresponds with the Lower Palaeozoic or Primary era—from the base of the Cambrian to the middle of the Carboniferous of Europe; and

IV, the *Aryan*, which corresponds to all the formations laid down in Europe since the Middle Carboniferous and thus includes the Mesozoic or Secondary, the Kainozoic or Tertiary, as well as the Quaternary, in which we are at present living. These four great eras of time, recognised by Sir Thomas Holland in the *Imperial Gazetteer of India*, vol. i, p. 55, 1909, are very suitable for the Indian formations and have been adopted by the Geological Survey of India, although they do not exactly correspond with divisions of the European geological record.

According to the scale adopted in Britain, and Europe generally, the Quaternary or post-Tertiary era includes all deposits since the close of the Pliocene, *i.e.* from the beginning of the Pleistocene, of which the epochs of time which have so far elapsed are known as Pre-glacial, Glacial, and Post-glacial (or post-pleistocene) respectively. Our epoch belongs to the Recent series of deposits, such as the alluvium of the Ganges plains and the deltaic area of Bengal, but does not include the older alluvium of the Narbada valley and the laterites of Midnapur and Malabar which are thought to be Pleistocene. The strata hitherto laid down during the Quaternary era, however, have not attained sufficient thickness to be represented satisfactorily on the time scale of Fig. 158B.

FIG. 158A. GEOLOGICAL TIME

[SINCE THE EARLIEST SEAS WERE FORMED AND THE OLDEST SEDIMENTS WERE DEPOSITED IN THEM]

TIME IN MILLIONS OF YEARS	EUROPEAN Eras and Periods		INDIAN Eras and Periods	
0	**Tertiary or KAINOZOIC**	Neogene Palaeogene	**ARYAN**	Siwalik Sirmoor Deccan Trap Bagh Beds Cutch Series Gondwana System Pir Panjal Trap
60	**Secondary or MESOZOIC**	Cretaceous Jurassic Triassic		
170	**Primary or PALAEOZOIC**	Permian Carboniferous		
250		Devonian Silurian Ordovician Cambrian	**DRAVIDIAN**	Kanawar System Naung Kangyi System Vindhyan System
500	**Pre-Cambrian, Algonkian, Transition or EOZOIC (Dawn of Life)**		**PURANA**	Cuddapah System Delhi System
1000	**Archaean, Huronian, Laurentian or AZOIC (Without Life)**		**ARCHAEAN**	Iron Ore System Aravalli System Mica Schists of Bihar Oldest Para-gneisses
1500				

? PRIMEVAL SURFACE OF THE EARTH

FIG. 158B. THE GEOLOGICAL (HISTORICAL) RECORD

MILLIONS OF YEARS	ERA	PERIOD	ANIMALS AND PLANTS		GEOLOGICAL EVENTS	INDIAN FORMATIONS	
0	**Quaternary** **1**	Pleistocene Pliocene	*Appearance of Man* *Largest Mammals*	*Present Day Flora*	*Sub-Recent Volcanoes and Ice Age in Northern Hemisphere*	Alluvium and Laterite	
	Tertiary **or** **KAINOZOIC** **60**	Miocene 25	*Horses, Sheep, Oxen, Dogs, Cats, Deer, Pigs, Elephants, Camels, Primates*	*Vegetation of very modern aspect*	*Continent of Asia established* *Uplift of Himalayas, Alps, etc.*	Siwalik Series	Kasauli Dagshai
		Oligocene		*Trees dominant over Herbaceous Plants*	*Igneous activity widespread* *Encroachment of Eocene seas*	Barail Series	Kirthar
50		Eocene 35	*Modern Marine Mollusc Fauna*	*Vegetation of Modern aspect*	*Break-up of Gondwanaland* *Deccan Trap Eruptions*		Laki Ranikot
100	**Secondary** **or** **MESOZOIC** **110**	Cretaceous 60	*Modern Fishes* *True Birds* *Last Ammonites and Dinosaurs* *Modern Insects* *Marine Reptiles* *Pterodactyls* *Toothed Birds* *Early Mammals*	*Spread of Angiosperms* *Ordinary Flowering Plants — Sycamore, Oak, Walnut, Willow, Fig, Palm, etc.*	*Widespread seas north of Indian shore of Gondwanaland* *Indo-African connection unbroken*	Lameta Beds	*Cardita Beaumonti* and Bagh Beds MADRAS E. COAST: Ariyalur Trichinopoly Utatur
		Jurassic 25	*Land Reptiles* *Sea Urchins* *Ammonites and Belemnites abundant* *Crabs*	*Incoming of Angiosperms*	*Westward extension of Burmese Sea* *Rajmahal and Sylhet Trap Eruptions*	**THE GONDWANA SYSTEM** Jabalpur Rajmahal	Umia CUTCH SERIES: Katrol Patcham
150		Triassic 25	*Lobsters* *Modern Corals,* *Ammonites and Belemnites*	*Cycads and Conifers* *Extinction of old forms*	*Afghan Submarine Eruptions* *Greatest spread of arid continents in Europe, Africa and India*	Mahadeva Panchet	*Monitis Beds* **LILANG SYSTEM**
200		Permian 40	*Spread of Reptiles* *Mammal-like Reptiles* *Last Trilobites and ancient Reef-corals*	*Ginko (Maiden-hair tree)* *Spread of Glossopteris Flora*	*Hercynian Earth folding* *Pir Panjal Submarine Eruptions*	DAMUDA SERIES: Raniganj Barren Beds Barakar-Karharbari	PRODUCTUS LIMESTONE: Chidru Jabi Kundghat Kalabagh Virgil Katha *Eurydesma Beds*
			Spread of Amphibians and ancient Sharks	*Calamites (Horse-Tails)*	*Ice age of Gondwanaland (Southern Hemisphere)*	Talchir	Boulder Bed Punjab Salt Range

250	**Primary** or **PALAEOZOIC** **330**	Carboniferous 75	*Early Insects* *Crinoids (Sea-lilies) abundant*	*Lepidodendron and Sigillaria (Club Mosses) Ferns* *Pteridosperms (Seed-bearing Fern-like Plants)* *Primitive Gymnosperms (Cordaites)*	*First Pir Panjal Eruptions* *Widespread igneous activity* *Marine conditions in Central Himalaya, Kashmir and Indian Borderlands generally*	GREAT PERIOD OF EROSION OF THE INDIAN PENINSULAR REGION	**KANAWAR SYSTEM** *Fenestella Sh.* PO SERIES *Syringothyris Lst.* LIPAK SERIES
300		Devonian 40	*Incoming of Spiders* *Goniatites, Amphibians, True Fishes and Scorpions*	*Pteridophytes (ancient spore-bearing Fern-like Plants)*	*Volcanic eruptions in many areas* *Caledonian earth folding*		Zebingyi Stage
350		Silurian 25	*Abundant Reef-corals and Ostracoderms* *First Land Animals* *Last Graptolites*	*Establishment of Land Plants*	*Seas present over parts of Upper Burma (Northern Shan States)—Kashmir and Central Himalayas*		Namshim Beds Panghsa-Pye Bed
400		Ordovician 60	*Abundance of Trilobites and Graptolites and Molluscs* *Incoming of Corals and Ostracoderms (Lampreys)*		*Widespread arid continental climates in Russian Angaraland, Persian and Indian regions*		NAUNG-KANGYI SERIES
450 500		Cambrian 90	*Dominance of Trilobites* *Well-developed Shell-bearing Molluscs* *First well-known Marine Fauna*	*Some Vitrain (Coal) Lenticles occur in the Vindhyans* *Algae Types of Calcareous Reef-building forms*	*Great period of uplift and erosion in Indian Peninsula* *Cuddapah Intrusions (Wajra Karur Pipe)* *Bawdwin Volcanic Series* *Malani Rhyolites*	VINDHYANS AND KURNOOLS TAWNG-PENG SERIES	Ngwetaung Sds. SALT STRATA Salt-Pseudo-Morph Beds Magnesian Sandstones PUNJAB RANGE *Neobolus Beds* Purple Sds. Purple Shale SALINE SERIES?

The Pre-Cambrian Sedimentary Rocks date back another 1000 million years, and since GEOLOGICAL TIME is reckoned from these it is about 1500 million years.

The thicknesses of the various series into which the rock systems are divided differ greatly in different parts of the world. The total thickness of the strata of Britain, from the base of the Cambrian to the Recent, is probably nearly 75,000 feet, or almost 14 miles. In India the Kainozoic or Tertiary formations in the Punjab and in Assam are alone more than half the total of the British fossiliferous formations. The Gondwana system is not less than 2½ miles thick—assuming 8000 feet for the Lower Gondwanas in the Damodar valley and 5000 feet for the Upper Gondwanas in the Satpura uplands. The rock formations of the Dravidian group in the Kashmir Himalayas are estimated at quite 14,000 feet, so that the total for the Indian fossiliferous formations may exceed that of the equivalent formations in Britain. To this must be added the thickness of the unfossiliferous strata of the two older eras—the Purana and the Archaean—which may be greater than that of the sediments of the Dravidian and Aryan groups.

Differences in Indian and European scales.—In India we find two distinct regions—the Peninsula and the Extra-Peninsula—the geological history of which differs considerably. The Peninsula has been a land region from a remote past, whereas the mountain chains, which comprise the Extra-Peninsula, consist largely of sediments of marine origin and formed part of the sea floor in early Tertiary times. When dealing with the geology of these two regions and trying to fit their history to the geological time scale of Europe, it has been found better to compare the fauna of the marine formations rather than the animal or plant remains of the land or river deposits. Also, seeing how in some areas sediments which were laid down in the sea have subsequently been raised into land and subjected to weathering, while at the same time in a distant area the reverse movement has occurred, it follows that interruptions or epochs of no deposition in one area may be fully represented by sediments in another area. And so it has been found that the **intervals** or " breaks ", where no record occurs, of the European scale do not correspond with the dominant breaks of the geological record in India. It is for this reason that we find " passage beds " between the Palaeozoic and Mesozoic, and between the Mesozoic and Kainozoic (Tertiary) where intervals or gaps evidently occurred in Britain and other parts of Europe.

Hardening of rocks.—The way in which the sands and clays transported by rivers settle down in the manner explained above and become hardened into the sedimentary, stratified rocks must now be explained. There are two great causes at work bringing about this result, *viz.*, the hardening by **pressure** and that brought about by **infiltration.** By squeezing some mud under a heavy weight, it is seen that the mud becomes drier and more compact as the weight is increased and the pressure prolonged. The great mass of deposited sediment, which is being added to continually, exerts an enormous downward pressure upon the bottom layers, causing them to become dry and compact.

The process of infiltration can be imitated by pouring lime-water on to some sand contained in a vessel, and then allowing the water to evaporate by placing it in a warm place. The lime dissolved in the water is deposited between the grains of sand, and binds them together as the mortar used by a mason binds the stones of a wall together.

In nature, too, water containing such substances as lime in solution percolates into the mass of the deposit, and by its evaporation a layer of the dissolved material is thrown down which effectually cements the incoherent mass, converting it into a hard rock. Generally, both these agents, pressure and infiltration, work together towards the same result.

Rocks formed from sediment deposited by water.—A characteristic feature of such rocks is the bedded structure or, as it is commonly called, their stratification, and hence the name stratified rocks, which is sometimes applied to them. This stratification or bedding is not so conspicuous in wind-blown deposits, such as sand dunes, and may be absent in the thick occurrences of calcareous clays of **eolian** origin, known as *loess*, which occur in China, Turkestan and elsewhere. They represent deposits of dust which have been blown into wide valleys and there settled as the wind dropped.

Rocks which have been formed in water are often called **aqueous** rocks to distinguish them from the aeolin deposits, but it is now not unusual to refer to all these consolidated sediments as sedimentary rocks. They fall into two main groups, known respectively as *arenaceous rocks* and *argillaceous* (clay) *rocks.*

Arenaceous (sand) rocks are derived from the insoluble form of silica—quartz—which results from the decomposition of igneous rocks (p. 275), and becomes separated from the other products by the action of running water. Names are given to different rocks formed in this way, according to the size of the constituent grains. The following are some of the chief :

Sandstones are composed of coarse and find grains of quartz, partly or wholly cemented together by different substances. Before this consolidation, the quartz grains constitute a *sand,* which may be dry and loose or damp and firm. A descriptive adjective is added to direct attention to the nature of the cement, thus, *ferruginous* or *red sandstone,* like some Vindhyan sandstones, in which the grains of quartz are held together by a red oxide of iron ; *calcareous sandstones,* in which the cement is carbonate of lime ; *sideritic sandstone,* where the cementing matrix is carbonate of iron ; earthy or *argillaceous sandstone,* in which clay acts as a matrix and weak cement. It may happen that the cement is secondary (colloidal) silica in which the rock, if locally hard, is an *indurated sandstone,* or, if wholly cemented, is a strong *quartzite* Most *freestone* and *flagstones* are sandstones which can be used for building and paving respectively. *Felspathic sandstones,* because of the mixture of grains of sand (quartz) and felspar, are especially useful for paving purposes. *Micaceous sandstones* contain flakes of mica along the planes of bedding. **Conglomerates** are deposits of pebbles and boulders of any type of rock and may occur in beds of considerable thickness, compacted by a cementing matrix of calcareous clay or calcium carbonate or other cement. It is, however, not uncommon to find such conglomerates largely composed of pebbles and boulders of true quartzite, as is the case in some of the Cuddapah, Vindhyan, Lower

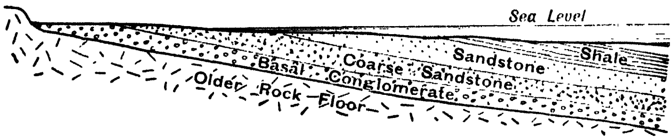

FIG. 159.—Diagram to show the order of the sediments laid down on a sinking coast.

Gondwana and Cretaceous formations in India. In the case of Glacial boulder beds of the Talchirs in the Salt Range of the Punjab, the boulders are not all of quartzite, and lie in a clay (tillite), showing that the boulders were dropped to the sea bed by floating ice (icebergs).

Argillaceous aqueous rocks *are derived from the most finely divided insoluble substances, such as kaolin or lithomarge, resulting from the decomposition of the constituents of igneous rocks* (p. 275). This class of rock comprises the different varieties of **clay**, hence the name *argillaceous* (Lat., *argilla*, clay). Kaolin is white, but other clays are of different colours, depending chiefly upon the amount of the oxides of iron present. The chief varieties of this class of rocks are :

Mud and **silt**, respectively, are the names given to the fine and somewhat coarser loose materials which settle in quiet waters. The former consists largely of clay, while the latter has a greater percentage of sand and other mineral grains. When more compact and plastic and freer of gritty matter the former often passes into clay, and may become softened by wetting. **Mudstone** is hardened, semi-consolidated mud with no disposition to split up into layers. **Shale,** on the other hand, is consolidated clay or mud, which can usually be divided into thin layers or laminae ; it does not soften or become clay-like by wetting. It is known as *carbonaceous shale* when it contains a sufficient amount of carbonaceous matter to give it a dark colour. It passes into *shaly coal* when the combustible carbonaceous matter exceeds 50 per cent. of the total weight Such low grade material may occasionally be used as fuel. Oil and kerosene shales are those which yield mineral oil on destructive distillation and occur in Burma.

Rocks formed by the aid of animals and plants.—Among the materials which water dissolves in favourable circumstances from rocks are silica (agate) and calcium carbonate (chalk). Neither of these compounds is considered soluble in pure water, and the first owes its solution to the presence of alkaline carbonates in the water, the latter to carbon dioxide (p. 297) derived from the air. As a result of this action sea water contains about 2½ grains of dissolved calcium carbonate per gallon, and an even smaller proportion of silica. Calcium sulphate (gypsum), which is much more abundant than either, is with difficulty soluble in water. It is often formed in nature by the interaction of sulphuric acid, which is liberated by the oxidation of sulphides (pyrites), and calcium carbonate (limestone). Variable quantities of the same compounds occur in rivers and lakes.

Either calcium carbonate or silica, obtained directly or indirectly * from the surrounding water, forms the main source of the hard parts —the shells or other supporting or protective structures—of many aquatic animals and plants. When the organism dies its soft parts decay; its hard parts accumulate if the circumstances are favourable, sometimes in sufficient quantity to form extensive deposits of **ooze** † over the bed of the sea. The calcareous shells of Pteropods and Globigerina accumulate to form ooze, and so do the siliceous skeletons of Diatoms. Each of these deposits gives an ooze distinctive of the deeper ocean floors.

Organic rocks composed of calcium carbonate.—Organic rocks formed by animals are much more abundant than those which plants build up. It will simplify the matter to consider first the work of plants in this connection:

(1) *Formed by plants.* Many minute seaweeds have the power of extracting calcium carbonate from sea water. The carbonate sometimes helps to make up parts of the plant itself, at other times it is deposited outside the organism only, forming an incrustation. Small rounded lumps of calcium carbonate, called *coccoliths* when single, or *coccospheres* when collected in massses, and formed in this way,

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* There is reason to suppose that the calcium sulphate, rather than the calcium carbonate, dissolved in sea water, furnishes the lime of the hard parts of marine animals. The calcium sulphate is apparently acted upon by ammonium carbonate produced by the animal, and thereby converted into calcium carbonate.

† The term Ooze is given to those deep ocean-bed deposits of fine, coherent, plastic mud which consist of the shells and skeletons of those minute organisms which when alive float in the uppermost 200 fathoms of the sea, but when they die sink into the abysmal floor of the ocean. The living organisms, consisting both of animals and plants and generally referred to as plankton, usually inhabit warm waters. Pteropods are characteristic of tropical waters and their calcareous, delicate shells are seldom found in sea floors deeper than 100 fathoms. Globigerina shells are larger and more robust, so that a Globigerina ooze may occur to depths of 8000 fathoms or more. The organisms classed as Radiolaria have siliceous skeletons, and although they may occur in warm waters, as do the Globigerina, their remains occur at greater depths than 2500 fathoms. The minute plant, whose siliceous skeleton is the Diatom, is common in deep, cold seas, and diatomaceous ooze occurs at abysmal depths, exceeding 2500 fathoms.

occur on the floor of part of the Atlantic Ocean. They also occur in masses of chalk.

Certain *oolitic* and *pisolitic* limestones—which play an important part in the topography of Great Britain and other countries—are composed of small rounded grains. All these limestones were supposed, until recently, to have been formed by the gradual deposition, from solution, of concentric layers of calcium carbonate around minute grains of sand or tiny shells. It is now believed that in some marine limestones the oolitic grains of calcium carbonate were laid down by a minute alga or seaweed.

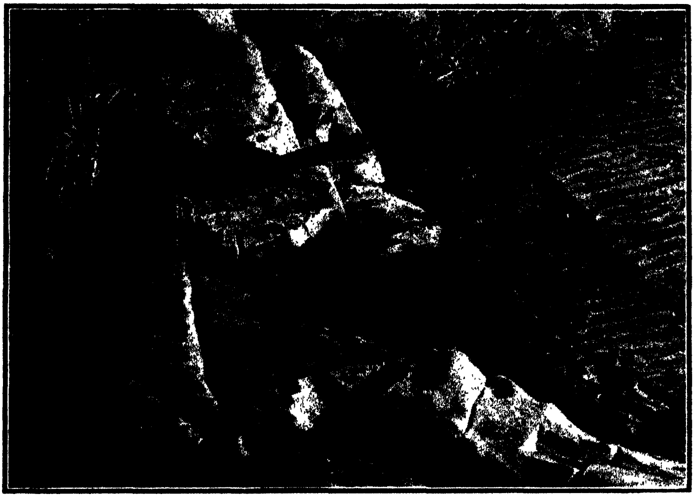

FIG. 160.—Surface of ancient sandstones (Vindhyan = Cambrian ?) showing effects of ripples due to water-wave motion. (With the permission of the Director, Geological Survey of India. Photo by J. A. Auden.)

(2) *Formed by animals.* Many animals extract calcium carbonate * from the waters in which they live, and use it to build their hard parts. All the so-called " shell-fish " do this, and their extinct relatives did the same. Some of the most abundant rock masses,

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* Footnote, p. 264.

such as the Nummulitic (Eocene) limestones in India,* have been built by the accumulation of the remains of very small creatures.

Chalk is composed chiefly of the skeletons of very lowly animals belonging to the group called *Foraminifera,* the most commonly occurring member of the group *Globigerina.* Although these animals were individually perhaps no larger than a pin's head, they occurred in such enormous numbers that certain very impressive features of modern landscapes are composed almost entirely of their remains.

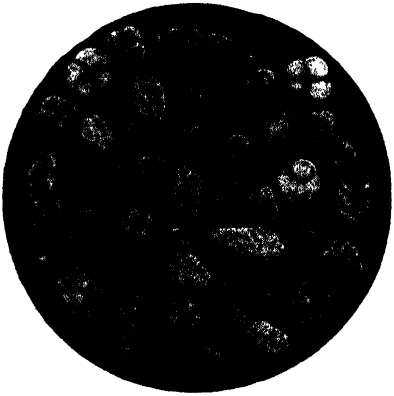

FIG. 161.—Foraminifera from Valdi Savena, Italy. (Magnified.)

The chalk which makes up great rock masses in the south-east of England as well as in other countries contains many such foraminiferal shells, with the larger shells of many other organisms, and was once held to be of similar origin to the abysmal ooze of the Atlantic Ocean. Chalk is now known, however, to have been formed at a much smaller depth than the ooze, and it should be noted that foraminiferal deposits to-day are also found in only moderately deep water.

Coral.—Other marine animals higher in the scale of life than the foraminifera, which also make use of the calcium carbonate extracted from sea water * for building up their hard parts, are coral polyps. They are related to sea anemones.

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* Sir Thomas Holland, writing of the Porbandar stone, states that: " One of the most interesting among sub-recent formations is the calcareous free-stone, largely used for building purposes in the Bombay Presidency, which is quarried from deposits that occur near Porbandar and other places on the Kathiawar coast. The rock consists largely of the remains of minute foraminifera, with small quantities of sand grains which have been transported by the wind from the sea-shore. Deposits of this nature attain thicknesses of 200 feet, showing their characteristic false-bedding, near Junagarh, which is 30 miles from the coast; but the foraminifera are carried much farther inland, being found as far as Bikaner in the Rajputana desert. The rounded and small shells of the foraminifera which make up such a large part of the Porbandar stone are often mistaken for oolitic grains, which also occur in the deposit." (*Imperial Gazetteer of India*, vol. i, p. 100, 1909.)

Coral polyps can flourish only in clear moving water which is not below a temperature of 68° F., nor at a greater depth than about 120 feet below the surface. Reef-building corals are not often found in latitudes much more than 20° from the Equator. These coral polyps live in colonies, and the result of their existence and reproduction is the formation of masses of coral, like that shown in Fig. 162. The **atolls** of the Laccadive and Maldive islands and other archipelagoes in the Indian Ocean are built up by recent coral. The coral seen on the coasts of the Andaman and Nicobar islands also forms massive rocks. Reefs made entirely of the skeletons of these coral animals are sometimes very extensive, as, for example, the Great Barrier Reef of Australia, which has a length of upwards of 1200 miles along the north-eastern coast of that continent.

FIG. 162.—A low, woody coral-reef, Outer Barrier, Australia.

*Footnote, p. 264.

Limestone is also often made up of calcium carbonate forming the remains of animals. It was secreted by them to form their hard parts. Among the stratified rocks there are many ancient beds of limestone which, when examined closely, are seen to be composed almost entirely of coral or other calcareous remains of animals. These highly fossiliferous limestones are of common occurrence in India and other countries. Thus the well-known Sylhet limestone from the Khasi hills of Assam consists very largely of the Eocene foraminifera *Nummulites* and is called the **Nummulitic limestone.** The equally widely-known Permian limestone of the Punjab Salt Range, which contains large recognisable shells, is named in consequence the *Productus limestone,* and belongs to the general class of **Shell limestone.** And among others may be mentioned the **Encrinital limestone,** which is made up almost entirely of the jointed remains of animals called sea lilies, closely related biologically to star fish and sea urchins. Some limestones occur in which the animal remains have been broken up and reduced to a mud (earthy limestone), and others in which crystallisation has taken place either as the result of great pressure or by percolating water.

Organic rocks composed of silica.—*Those formed by plants.* These plants are known as **diatoms.*** They are generally microscopic in size, but have existed in sufficient numbers to form, by the accumulation of their hard remains, beds of considerable thickness. Their hard framework is made of the silica which the living diatom extracted from the water (either fresh or salt) in which it lived. At Richmond, in Virginia, beds of forty feet thick occur, and these consist entirely of the remains of diatoms. *Diatomaceous earths* and *Tripoli powder* have been made in this way.

Sinter, the siliceous precipitate which frequently deposits from the waters of some hot mineral springs, may, in some cases, be due to algae which are believed to live in such hot waters and extract the silica from the mineral water.

Those formed by animals. Silica-secreting animals, like foraminifera, belong for the most part to the group of simplest animal structure known; they are called **Radiolaria.*** Their remains build up the *Radiolarian earths* which occur in various places. A good instance is provided by the radiolarian earth of Barbados. Certain sponges, called siliceous sponges, also have this power of extracting silica from the water in which they live. They utilise the silica to form the *spicules* commonly associated with the remains of radiolaria.

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* See footnote, p. 264.

Organic rocks composed of the remains of land plants.—These rocks are sometimes called *Carbonaceous rocks,* and include peat, lignite, coal, also the brown, so-called bituminous coals, anthracite and graphite.

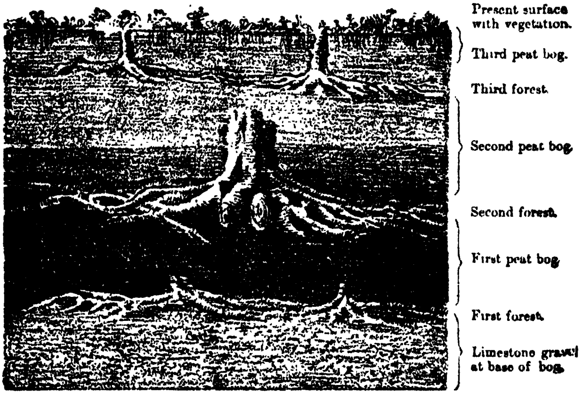

FIG. 163.—Section of an Irish peat moss.

Peat, which is often stated to be the first stage in the formation of certain varieties of coal but which has still to be proved to be so, has none of the characters usually associated with rocks, and is included here because it is often a valuable fuel and helps to complete the stages in the formation of coal. If obtained near the surface of the ground, peat is an incoherent mass of vegetable fibres. As it is traced further below the ground surface it becomes more compact, gradually assuming a darker appearance. It is formed in bogs and marshes, usually under water, or at least is soaked in water. Judging by the mode of formation of peat in Ireland, it appears that water-loving plants, like certain mosses, by their rapid growth, gradually encroach upon the open water of the marsh round which they grow, until eventually it may be obliterated, its place being taken by a mass of vegetable matter, still growing on the top, but composed beneath of the accumulation of the dead parts of the plants of previous years. Such areas constitute **peat mosses or bogs.**

Bogs are abundant in temperate countries where the conditions often favour their formation. True peat occurs in India, in the Nilgiri hills, and though the material is useful as fuel the deposits have not been largely opened up. A section of an Irish peat bog, showing the growths of three successive submerged forests, is given in Fig. 163. The so-called " peat " which is found at a depth of about 40 feet under most parts of Calcutta consists largely of drifted vegetable material and belongs to the class of true sedimentary deposits, like many of the coal seams of India. However, a section of the strata below Calcutta reveals the presence of the stumps of trees in the position in which they grew, but they are in clay and not associated with the " peat ".

Lignite.—If the land on which a peat bog has been formed subsides to any extent, it will become covered probably with water, and there may be deposited above it a bed, or beds, of sedimentary rock, as is evident in the section of the Calcutta strata containing " peat ". This bed of rock will subject the vegetable mass to pressure, and cause it to become compacted further. The form then assumed is that of a brown or black rock in which the woody material, trunks of trees, etc., is still recognisable. The Palana lignite of Bikaner is brown and resembles peat ; that of Makerwal is dark brown to black and looks like coal ; that of Makum, in Assam, is jet black. All these lignites or lignitic coals, which are of Tertiary age in India, give a brown streak when rubbed on a white, rough, porcelain surface, and so, whether brown or black in colour, hand specimens are spoken of as *Lignites* or *brown coals*.

Coal.—The true coals give a black or dark grey streak when rubbed on a white matte surface. They usually occur in strata of Palaeozoic age—of the Upper Carboniferous period in Britain and the Lower Gondwana (Permian) period in India. The Lower Gondwana (Damuda sub-system) coals appear to have been formed by the accumulation of vegetable matter in large lakes or great swamps in wide river valleys. The plant material was evidently derived from great forests which grew in the basins of the lakes and rivers and was swept into the depressions during periods of flood. Most of the material thus appears to have drifted, but some may have grown on the margins of the swampy depressions and have fallen in and added to the débris.

It is evident that for the accumulation of 5000 or 6000 feet of coal-bearing strata, a great deal of subsidence of the land must have occurred, but this regional sinking of the Indian region in Lower Gondwana times does not appear to have permitted the sea to enter any of the basins where the Indian Gondwana coal seams were being laid down. The thickness of the lowest, or Barakar stage, of the Damuda strata is over 2000 feet and contains at least 24 seams of coal, each more than 4 feet thick (many are more than 20 feet thick), in the Jharia coalfield. The deposits of vegetable matter were covered in turn by silts, sands and clays. The pressure of the overlying strata has played a great part in converting the plant débris into coal, and it is possible to detect the effects of pressure by the composition of the coal—those of high volatile content being less deeply buried than those with a low volatile percentage. The cycle of coal seam formation was entirely one of subsidence but at an unequal rate. Thus, sands and gravel beds were formed in shallow, rapid-flowing water, the clays in deeper, quieter waters, and the vegetable débris in deep stagnant waters. The mode of formation of the lignitic Tertiary (Kainozoic) coals of India appears to have

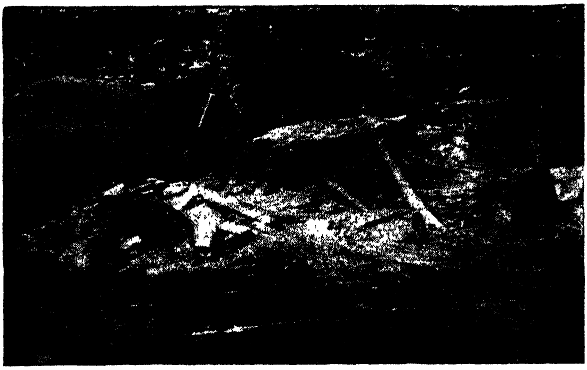

FIG. 164.—Fossil tree stumps (*Stigmaria ficoides*) of giant club-mosses of Carboniferous age (coal measures) at South Yorkshire Mental Hospital, Wadsley, Sheffield. (By courtesy of Professor W. T. Gordon.)

been similar to the coals of the Carboniferous of Britain ; these were laid in estuaries or in the sea during a period of subsidence.

The vegetation of the Lower Gondwana period included a much larger proportion of **cryptogams***—plants which do not produce flowers or seeds—than is found at the present day. The cryptogams of the Carboniferous coal-measure period of Britain include ferns, horsetails, club-mosses, true mosses, and others ; but in the flora of the Lower Gondwana (Damuda) coal-measure period large trees, 75 to 100 feet high, also existed and their fossil trunks are of the genus *Dadoxylon.* By far the commonest plant fossils of the Damudas are leaves which are referred to the genus *Glossopteris.* But notwithstanding close search it is not yet possible to say if the *Glossopteris* leaves grew on the *Dadoxylon* trunks nor is it possible to draw a picture of the plant which carried the *Glossopteris* leaves. A study of some of the Barakar and Raniganj stage coals of the Damuda series has shown that a considerable amount of woody material has been incorporated in the material now found as coal. Thus the Lower Gondwana flora was in many respects very different to the *Lepidodendron* flora of the Upper Carboniferous of Europe, and to show the difference, we speak of the Indian coal-measure (Permian) flora as the *Glossopteris* flora. Upright tree stems with attached roots have not been recorded from the Indian Gondwana coal measures. Plant remains, as fossils, are common in some of the shales, but leaves attached to twigs are rare, and any animal remains are very rare indeed. None have been found in the coalfields, in spite of the development of collieries.

Much work has been done upon " coal balls ", which are more or less spherical masses of calcareous clay in which occur many stems, leaves and seeds of various coal plants. Remains of the whole plant are found replaced and cemented together by calcium carbonate. These coal balls, which occur associated with many of the coals in England and elsewhere, show the replaced cell structure of the contained plant fragments so well, that the botany of those plants is now becoming well known. It has been shown that many plants, until recently considered to be ferns, formed seeds ; and the old idea that all coal plants were cryptogams has been given up. Unfortunately such "coal balls" have not been found in the coal measures of India. The name is sometimes confused with the term "ball coal" (*i.e.* nodules of coal), which is a form of spheroidal jointing in some seam which produces balls of coal ; it has no relation whatever to the "coal balls" of English coal seams.

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* Relatives of most of the cryptogams which formed the coal are found living to-day, but they have now little importance compared with the *flowering plants*, which include not only plants bearing " flowers ", as the word is ordinarily understood, but also all our forest trees and grasses, as well as the commonest weeds. Coal is often spoken of as being formed from ancient forests, but it should be remembered that very few trees, as we know them now, grew at the time when the plants, which formed the English coal, flourished. It is, however, a fact that some flowerless plants, allied to club-mosses and horsetails, then grew to a great size, and were as large as some of our trees.

Fig. 165.—Stalactites and stalagmites in Cox's Cave, Cheddar, Somerset.

Anthracite is a very high grade of coal of low volatile content. Under great pressure the ordinary, so-called bituminous coal loses more and more volatile matter and passes through a stage of semi-anthracite to anthracite. It has been shown that some of the properties, such as very low ash percentage, of the South Wales anthracite must indicate a special kind of plant material in the original accumulation. It contains a greater percentage of carbon and a smaller amount of hydrogen in 100 parts than ordinary coal. It is sometimes called smokeless coal, because of the way in which it burns. Except for locally formed anthracite in the Tertiary coal seams of Kashmir, which have been squeezed with the containing strata in the Himalayan folding, there is no commercially exploitable anthracite in India.

Graphite.—If everything but the carbon is expelled from good coal by the action of great pressure and heat, the final result may be very like the variety of carbon known as graphite. True graphite, like that obtained from the mines in Ceylon and often found associated with so-called metamorphic and other rocks which have evidently once been deep within the earth's crust, could never have been formed from coal nor from plant remains. The rocks in which the graphite occurs are generally far older than the oldest fossiliferous rocks and belong to a period before life appeared on this earth. Graphite occurs in some meteorites which fall on the earth from planetary and perhaps interstellar space.

Aqueous rocks formed by chemical means.—Rocks formed by deposition of calcium carbonate from solution in water are **stalactites** and **stalagmites** (Fig. 165). These are chiefly due to the evaporation of water dripping from the roof to the floor of limestone caves and thus forming hanging masses and pillars respectively. Often they combine to form solid columns of calcium carbonate.

Calcareous tufa or travertine.—More generally deposits of *tufa* are formed where calcareous spring waters occur or where waters heavily charged with calcium carbonate are exposed to evaporation as they flow in wide, shallow stream beds or gently discharge over cascades or banks. Some of these deposits make curious natural dams, which impound the river water and make lakes, such as those of Nam Tu in Upper Burma and Bund-i-Amir in Afghanistan.

Beds of *rock salt* are generally due to the precipitation of sodium chloride from sea water which has become concentrated in a shallow bay or gulf under the evaporation of the sun's heat. If a bar across the mouth of a gulf allows sea water to enter, as the level of the sea in the gulf falls by evaporation, such as in the Kara Baghaz in the Caspian, a great thickness of salt may accumulate on the floor of the gulf before it becomes filled with such salt. In the case of Sambhar lake the supply of salt is carried by the wind from the Arabian Sea and deposited over the desert sands, from which it is washed out by rain and carried into the lake basin, where it becomes concentrated, and, in the hot months of the year, is deposited by evaporation of the lake water. The beds of *gypsum*, found associated with the rock salt in the salt mines of the Punjab Salt Range and in the Kohat district in India, and in salt deposits elsewhere, are believed to have been precipitated from sea water in the same way as the salt. There are other places in which gypsum occurs, especially the crystals of *selenite*, due to the interaction of calcium carbonates and forming calcium sulphate with the sulphuric acid liberated from decomposing sulphides, *e.g.* iron pyrites. When fresh-water lakes, such as that of Lonar in the Deccan, have no outlet and undergo desiccation, the precipitate formed on the lake floor is usually of sodium and magnesium carbonates. It is possible that some *dolomite* may be formed in this way, but usually its history is far more complicated.

23. UNSTRATIFIED ROCKS

1. Igneous rocks.—(*a*) Examine a piece of *granite*, such as is often used in blocks for masonry or as paving-stone. Observe the minerals of which it is composed. The clear, glassy, crystalline grains of *quartz*, the whitish or flesh-coloured crystals of *felspar*, and the dark or silvery shining crystals of black or white *mica*, or sometimes the greenish grains of *hornblende*.

Break up a block of granite and notice that there is no sign whatever that it consists of layers.

(*b*) If possible also examine other igneous rocks—such as *dolerite*, *charnockite*, *rhyolite*, and *basalt*. Classify them as obviously coarse, medium or fine grained, or even glassy in texture. Have any of these rocks any resemblance to slag?

2. Metamorphic rocks.—(*a*) Examine a piece of *slate*. Test it with careful blows with a hammer in different directions.

Try the effect of a drop of acid on it.

(*b*) Similarly examine and test a piece of *marble*, as well as a hard specimen of *quartzite*.

(*c*) Study the surface of these rocks with the help of a lens. Can you see any evidence that the rock has become crystalline?

(*d*) To which of the stratified rocks, limestone, shale or sandstone, do you think the three metamorphic rocks examined have respectively the most resemblance? Give reasons for your conclusions.

Igneous rocks.—These rocks include all which have at some time in their history been in a molten state or have cooled and crystallised from a highly heated condition. Their physical character or texture, *i.e.* their glassy or crystalline nature, depends almost entirely upon the *rate* at which they have cooled. In those cases where the cooling has been comparatively rapid, as, for instance, with the lavas poured out from volcanoes, what are called **volcanic** rocks are obtained; in these crystallisation is only rarely perfect, with the result that they are seldom coarsely crystalline. Usually they are fine-grained, and sometimes they consist largely of a glassy material.

FIG. 166.—View of two dykes of dolerite across the Denwa river east of Pachmarhi, Central Provinces.

Examples of such **volcanic** rocks are: (*a*) *obsidian*, an acid volcanic glass, which is often not distinguishable in appearance from some kinds of bottle glass; (*b*) *basalt* (Fig. 138) is a fine- to medium-textured basic volcanic rock which covers 200,000 square miles of the Deccan as lava flows; (*c*) *andesite*, which takes its name from the Andes mountains, closely resembles basalt but is less basic in composition. Andesites are perhaps the most abundantly found of all the igneous rocks, and a large part of the Deccan basalts are, strictly speaking, andesites or andesitic lavas.

In those rocks, however, where cooling has been slow, as is the case with those which now fill the channels through which the lavas flowed to the surface and those which have cooled deep down in the earth's crust, under the great pressure caused by the weight of the overlying layers, crystallisation is often perfect, and there is no glassy material present. Such rocks are termed, respectively, **hypabyssal** and **plutonic.** **Granite** is always considered as the typical plutonic rock. **Dolerite** on the other hand is undoubtedly a true hypabyssal type of igneous rock. There is no sharply defined line of demarcation between volcanic, hypabyssal, and plutonic igneous rocks; they merge the one into the other; thus *gabbro* is the coarsely crystalline plutonic rock of which *dolerite* is the **hypabyssal** or **dyke** form, connecting it with the volcanic *basalt* lavas of the surface. Great dykes may have gabbro in the middle, grading to each margin through dolerite and basalt to tachylite (the glassy form). Although the crystalline texture thus varies enormously, the chemical composition of all these four may be identical.

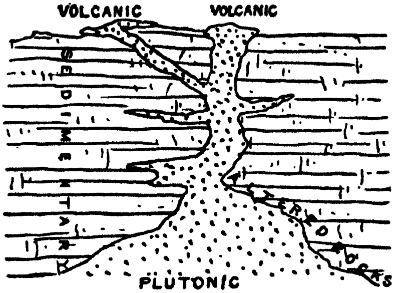

FIG. 167.—Volcanic rocks are lavas cooled near the earth's surface. Plutonic rocks are lavas cooled deep in the earth's crust.

Metamorphic rocks.—All rocks classed under this heading are *changed* or *altered rocks*, in the sense of modification by heat or pressure, but not due to any weathering action. The changes have been brought about both in sedimentary and igneous rocks by a variety of causes, such, for example, as heat by contact of an intruded mass of molten rock ; or by the pressure accompanying the great movements which have from time to time taken place in the earth's crust (p. 287). There is a great diversity in character among the rocks of this class.

Igneous, sedimentary and metamorphic rocks are dependent upon one another. Their interdependence becomes apparent when it is remembered that in many cases the materials necessary for the formation of the sedimentary rocks are obtained from igneous rocks, and that these stratified rocks may, under the influence of the changes mentioned, give rise to rocks styled metamorphic, which in some cases can only, with difficulty, be distinguished from igneous rocks.

Those changes which cause a sedimentary rock to lose its original texture completely and to become crystalline are classed as *metamorphic changes*, and are said to be due to **metamorphism.** Such metamorphism is the result, as a rule, of two important causes. First, that due to the heat to which the rocks become subject if forced far down into the earth's crust, or, more locally, to heat of contact with great masses of intruded molten rock. Nearly 400 million tons of good coal in the Jharia coalfield have been converted into unworkable natural coke by the intrusions, as sills, of a curious peridotitic type of igneous rock, in the coal seams, in bedding planes between the seam and the covering rock, or sometimes along the floor of the seams.

Secondly, the change may be brought about by the action of enormous pressures by the "dead" or static weight of the superincumbent strata, or to the dynamic squeeze which is the outcome of slow movements of the earth's crust.

A change may often be brought about by the chemical action of hot mineral waters at some considerable depth whereby induration, replacement, or simply crystallisation of the original sedimentary rock, may be effected.

Where metamorphism has been fairly complete, *sandstones* are changed into **quartzites.** Though hand specimens and sections under the microscope both reveal the origin of quartzite from quartz grains, yet these minute fragments are cemented together firmly, and the rock cannot be pounded up like a sandstone. It breaks with difficulty, and the fractured surface shows the interlocked grains broken across.

By pressure metamorphism *chalk* and impure and other **limestones** may be changed into **marble** or *crystalline limestones.* Though typical marble is white, it may, as the result of impurities of one kind or another, be of almost any colour—including black—and be handsomely veined in green or red or other tints.

The effect of pressure metamorphism upon *clays* and *shales* is to change them from a rock easily divisible into laminae along the planes of bedding, into one known as a **slate,** exhibiting the phenomenon of *cleavage*. The slate seldom splits along the original bedding planes, but along a new set which may be at any angle to the original bedding.

24. THE SLOW MOVEMENTS OF THE EARTH'S CRUST

1. The result of lateral pressure on strata.—Arrange differently coloured rectangular pieces of damp cloth in a heap, and place a piece of board of the same height as the pile at each end of the heap. Place a third piece of board, or a book of a suitable size, along the top of the pile with a weight on it. Now apply a lateral pressure, by pushing with both hands simultaneously against the end pieces of board, and notice the folding of the layers of cloth.

2. Outcrop, strike, dip and escarpment.—Make a tidy pile of a heap of books lying on their sides; they represent horizontal strata. Now push them over so that they lie on a flat surface as in Fig. 168; they now simulate inclined strata, and the upper surface of the pile is made up of the succession of the front edges of the books. Such an edge of each book at the surface represents an *outcrop*; the direction in which the edge of a book points is its *strike*; the angle the covers of the books make with the horizontal is the *dip*. Arrange the books so that the dip is small (*e.g.* 10°), and let them overlap; then the upper cover of each book represents the *dip slope*, and the upper edge of the book represents the *scarp slope*, of an *escarpment*.

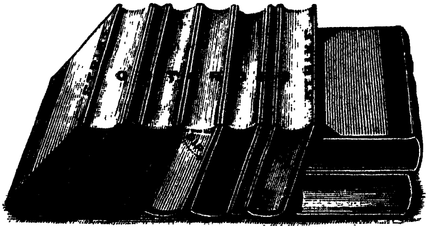

FIG. 168.—To illustrate the terms outcrop dip, and strike, applied to strata.

Slow movements of elevation and depression.—The earth's land or rock surface is quoted popularly as an example of stability, while the ocean is looked upon as ever changing its level. We have now to see that in reality this is not true of the land. The expression *terra firma* is founded on a misconception, for the land level is changing continually, being raised in some districts and depressed in others. The sea level on the other hand is, in a relative sense, more constant, so that it is properly used as a base or datum level from which heights and depths may be reckoned.

Since the movements of the land just referred to are very slow, and extend over great periods of time, they are called **secular movements.** They result eventually in a complete alteration in the shore lines of land and water. New stretches of land are formed by the gradual upheaval of the floor of the sea, while in other parts, owing to depression of the land, the sea encroaches and submerges tracts of country bordering the ocean : for example, in Lower Tertiary, Eocene times, when the curious foraminifera *Nummulites* were so prolific in tropical seas, the Nummulitic sea extended southward from what is now Kashmir over the Punjab and Rajputana to Surat. To-day the Nummulitic limestone is seen tilted at a considerable angle near Surat, and it occurs 200 feet beneath the surface near Bikaner, while it may be seen at heights varying from 4000 feet or more in the Simla hills to as much as 20,000 feet above sea level in the Kashmir Himalaya.

Recent evidence of rises and subsidences.—Discussing the Indian region Sir Thomas Holland wrote as follows : " Within India proper there have been local changes in the relative level of land and sea within recent geological times, in some cases connected with earthquakes, as in the case of the earthquake of Cutch in 1819, when a part of the Rann was submerged, and in the Assam hills, among which alterations of level and horizontal distance were detected by measurements after the great earthquake of 1897. The Andamans and Nicobars have been isolated from the Arakan coast by submergence at a probably recent date."

" On the east side of Bombay Island trees have been found imbedded in mud about 12 feet below low-water mark, while a similarly submerged forest has been described on the Tinnevelly coast. On the other hand, there is evidence to show that a part of the coast of Tinnevelly has risen and driven back the sea in the neighbourhood of Kayal. Again, the accumulations of thick masses of old alluvium in the rocky basins of the Narbada and Tapti rivers indicate changes in the relative levels of the upper or eastward, and lower or westward, parts of these basins."

Proofs that the level of the land is being raised in some parts of the earth are of several kinds:

(1) *The beds of sea shells, similar to those of animals still living in the sea, found near the coasts of various countries, but raised to different heights above the sea level.* Along the coast of South America such shells are found at a height of 1300 feet; in Norway up to 700 feet; and along the shores of Sweden at elevations varying from 100 to 200 feet.

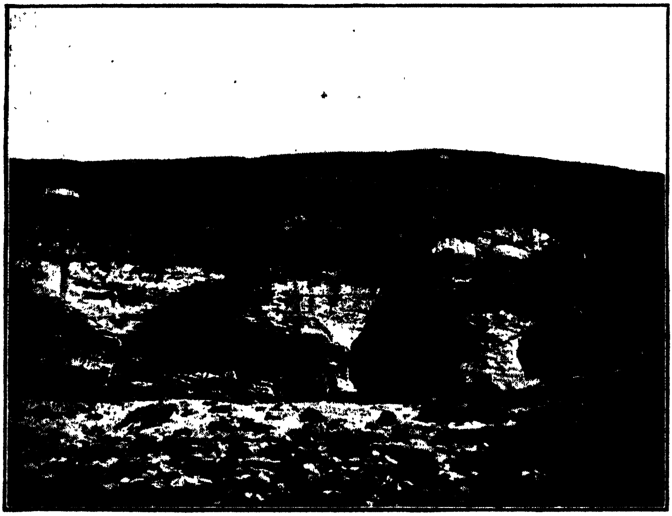

FIG. 169.—Old sea caves cut in the sandstone cliffs at the edge of a raised beach, Drumadoon, S.W. Arran. (Photographed by the Geological Survey of Scotland.)

(2) *The raised beaches which occur round the coasts of Britain and other countries.* These old sea terraces were evidently at one time at the margin of the sea. This fact is placed beyond a doubt by the water-worn rocks constituting the old sea-caves which often form the background of such beaches. Raised beaches of this kind occur at various places round the Scottish coast (Fig. 169) and in one or two places round England. In Fife, three beaches, at 25, 50, and 100 feet above sea level, can be traced for considerable distances. Good examples are also to be found in the north of Norway, where a whole series occurs up to a height of more than 600 feet.

(3) *The present elevated position of certain human erections which were originally at the sea level.* A good example is afforded by the old Greek docks, which are now found much above the sea level on the southern coast of Crete.

Proofs that the level of the land in some parts is sinking:

(1) *The present position, below the water, of certain human erections which were built originally above the sea level.* This is true of several old streets of some seaports on the south coast of Sweden. The poles which the fishermen of Greenland in past times have put into the beach as an attachment for their boats now lie useless below several feet of water. Similarly, new posts are being put in continually to take the place of those which become submerged as the land sinks.

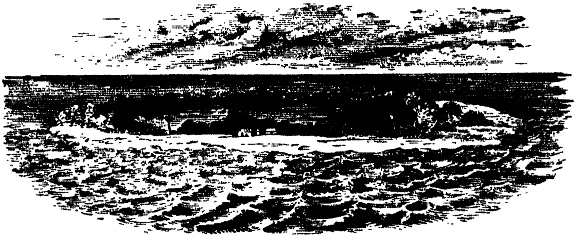

FIG. 170.—A typical atoll. See also Fig. 173.

(2) *The submerged forests which are not uncommon round the coasts of Devon, Cornwall and other places.* From the nature of the trees which make up these forests we are quite sure that they must have once lived on the land. Their present position gives an unmistakable proof that the land is sinking in these parts, or, at all events, has sunk in past times.

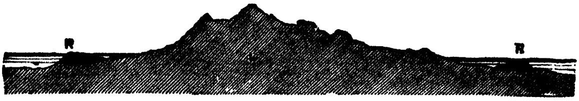

FIG. 171.—Section of a fringing coral reef.

(3) *The existence of coral at a depth of as much as* 1800 *feet in certain coral reefs, though it is well-known that the coral polyp, which builds the coral, cannot live below a depth of about* 120 *feet.* It was suggested by Charles Darwin that coral reefs afford proof of the subsidence of the land in the districts where they occur, though this has been denied.

On Darwin's theory the coral polyp must have commenced its work at a depth of about 120 feet, and have built upwards at something like the rate at which the land was sinking. At first the coral would form a ring round the island, such as is seen in section in Fig. 171. This stage is known as that of a **fringing coral reef.** Now imagine the island, *L*, to sink gradually as a whole. This would carry the fringing reef with it. But the coral polyps continue to build all the time and raise the reef to the same extent as the land subsides. They also build more quickly on the outside, where the supply of food is best maintained, and as a result the fringing reef gradually assumes the **barrier reef** stage (Fig. 172), where a small island is surrounded by a circular coral reef.

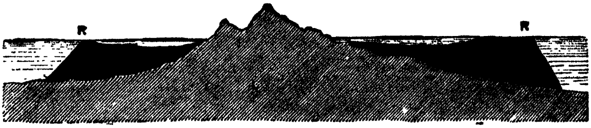

FIG. 172.—Section of a barrier reef.

The continuation of the same process eventually carries the island, *L*, completely beneath the water, and all that is seen at the surface is a circular island of coral, known as an **atoll,** as in Fig. 173, such as those which make up the islands of the Laccadive, Maldive and Chagos Archipelagoes in the Indian Ocean.

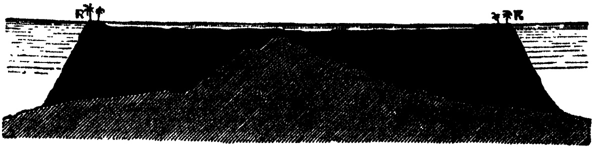

FIG. 173.—Section of an atoll.

Continental elevation.—In all parts of the world large tracts of country are found to show sedimentary rocks beneath the soil. In the strata it is not uncommon to find deep sea, shallow marine, estuarine and fresh-water deposits, giving evidences of many changes of sea level in past ages. On definite horizons, beds with characteristic fossils, such as the Nummulites, occur, and indeed the whole sequence of beds has been divided into systems, series, stages and zones (Fig. 158), many of which can be traced from one country to another. There are often unconformities in the bedding and interruptions in the life records (fossils), and the whole forms a most fascinating story of upheaval, depression and deposition in repeated cycles. If our knowledge were more complete it would be possible to obtain clear ideas of the geography of the world in all the different periods. Our present geography, known so much more definitely by us, is but that of the last of these periods.

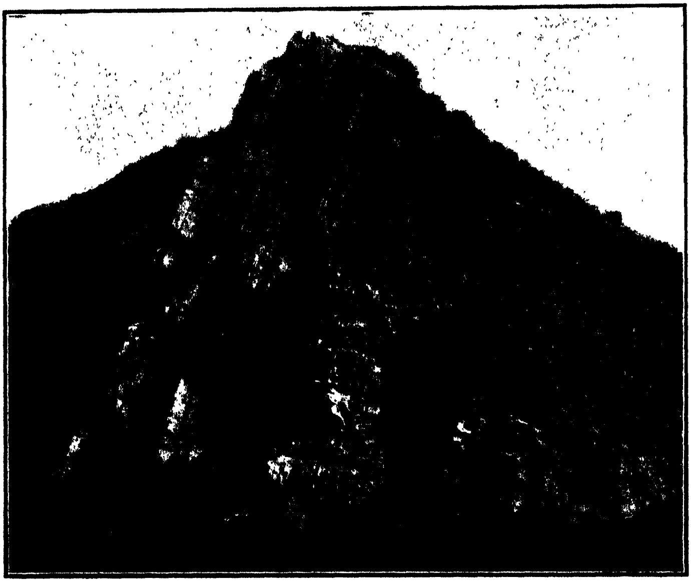

FIG. 174.—Tilted ancient strata (quartzites), Rajputana. (With the permission of the Director, Geological Survey of India. Photo by A. M. Heron.)

Let us, however, select one case from a multitude of instances. Much of the Deccan and Western India is built up largely of a great series of basaltic lava flows, which extends right across the Indian peninsula from Bombay to beyond Nagpur and less continuously into Bihar. In few places is there any great departure from horizontality, showing that the rock has been subjected to no violent movements. Yet from the nature of the lava flows and the manner in which they flooded the land surfaces, it is certain that when these lavas were being erupted the Deccan was already a land surface,* and yet we see these same lavas dipping steadily into the sea at Bombay. It is presumed that these lavas also cover a large part of the floor of the Arabian sea, owing to the land in that direction having subsided while the Deccan was lifted. The reasons for this belief are that the Nummulitic limestones rest discordantly or unconformably on the basaltic lavas near Surat well above sea level. There can be little doubt that the tract we call the Western Ghats has been elevated and, in consequence of its position, subjected to the sculpturing power of atmospheric denudation (p. 297). It can also be shown that the so-called Shillong plateau (or Assam range) has been elevated since Middle Tertiary (Miocene) times, without any serious folding of the Cretaceous and Nummulitic strata which lie above the great southern scarps which face the plains of Sylhet. From the consideration of such cases as these we are led to the conclusion that **continental elevation** may be brought about without any extensive fracturing or crumpling of the rocks. The folding or faulting is

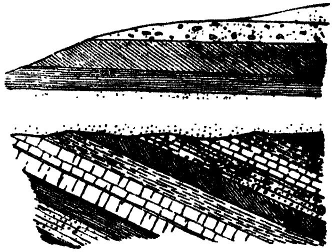

FIG. 175. — Uncomformable strata. From " An Introduction to Geology ", by Prof. W. B. Scott. (Macmillan.)

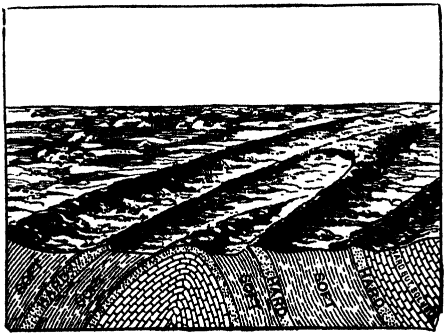

FIG. 176.—Perspective view and vertical section of Anticlinal beds. (From a *Report of the U.S. Geological Survey.*)

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* In spite of the fact that the Deccan lavas rest upon marine Upper Cretaceous strata—the Bagh beds—in Central India, the opinion of the Geological Survey of India is that the Indian peninsula has been a continental region since before Cambrian times, as no fossiliferous marine formations of a later period had been discovered within its inner borders. This view was somewhat shaken by the finding of Upper Palaeozoic marine fossils above the Talchir boulder bed in South Rewa, but on a careful examination of all the evidence the official view still holds good as a general consideration.

generally restricted to narrow belts of dislocation or bending in such cases as have been mentioned.

Other positions of stratified rocks.—Though geological formations may retain their original horizontal arrangement (Fig. 175), they have been subjected more commonly to some degree of movement resulting in what are known as inclined and vertical strata. When the originally horizontal strata have, in consequence of movements in the earth's crust, been pushed up so as to become inclined at an angle to the horizon, they are called **inclined** strata (Fig. 174). When this angle is a right angle the strata are spoken of as **vertical**. In some cases, as in the sections about Tindharia on the way up to Darjeeling, the order of the beds has been reversed completely, the older and first deposited stratum has been so uplifted as to overlie the younger, later beds; in such a condition of things we have **inverted** strata. (See *D*, Fig. 178.)

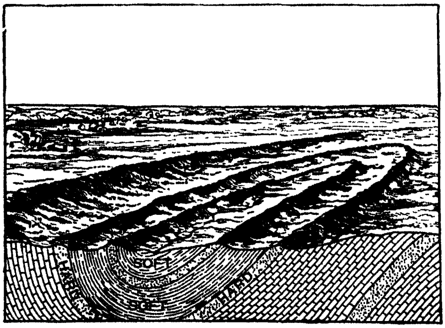

FIG. 177.—Perspective view and vertical section of Synclinal beds. (From a *Report of U.S. Geological Survey*.)

The angle which inclined strata make with the horizon is called the **dip** of the beds. In the case of horizontal formations the dip is, of course, nothing; while that of vertical beds is 90 degrees. In mining operations, where work is confined to highly tilted beds or inclined mineral veins, the slope of the plane is usually referred to a vertical plane, and the inclination is spoken of as the **hade** of the vein. A dip of 45 degrees is the same as a hade of 45 degrees; but a hade of 15 degrees means a dip of 75 degrees. In some cases strata lie horizontally, or nearly so, upon the upturned edges of other strata, as in Fig. 175. The stratifications thus do not agree with one another, and are therefore said to be discordant, or, more usually, **unconformable**.

Outcrop.—The extent to which a bed is seen at the surface depends upon the size of the angle of the dip and the thickness of the bed, as well as upon the surface contour of the country. When a series of strata is horizontal, it is apparent that only the uppermost bed can appear at the surface, until, at all events, some part of the bed immediately beneath becomes exposed by the washing away of parts of the surface stratum. When beds have become inclined, however, each bed in succession is found at the surface and the smaller the angle of dip the wider, in general, will be the part of the bed exposed. This exposed portion the geologist calls its **outcrop.** The width of the outcrop, then, is least for vertical beds, and in this case only is it an exact measure of the thickness of the stratum. The point of the compass to which the outcrop on a horizontal surface points is called the **strike** of the stratum in question.

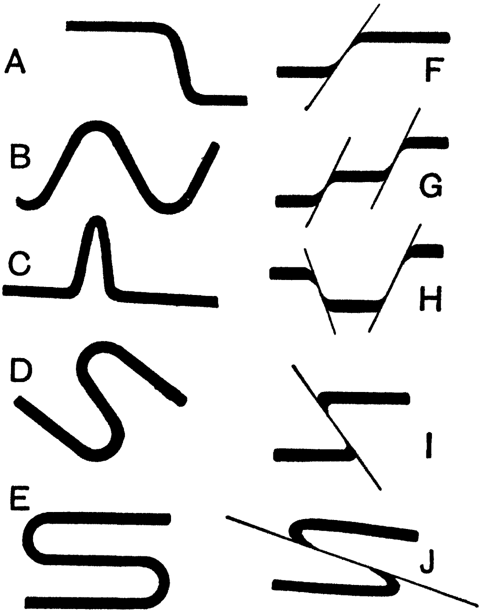

Fig. 178.—Sections of folds and faults.

A, Monoclinal fold; B, Symmetrical fold (Jura type); C, Upward fold (Afghan type); D, Overfold; E, Recumbent fold; F, Normal fault; G, Step faults; H, Trough (Rift Valley type) faulting; I, Reversed fault; J, Over-thrust fault (thrust plane).

In observations of the dip of the individual members of a succession of beds it often becomes very noticeable that there is a gradual diminution in the size of the angle, indicating that, in reality, the exposed parts of the bed are parts of large curves, or folds, into which the strata have been thrown by great movements in the earth's crust. Such folds must next be considered.

Folding of strata.—When horizontal strata are subjected to enormous lateral pressures, as a result of the great movements of the earth's crust, they become thrown into folds in a manner which can be easily imitated by Expt. 1, Sect. **24.**

Illustrations showing various forms of folds are shown in Fig. 178.

A is a *monoclinal* fold—a good example is afforded by the structure of the Khasi hills section between the plains of Sylhet and the Cherapunji plateau to the north.

B is a typical symmetrical fold, which is more commonly seen in illustrations of Tibet than in field studies of Himalayan mountain flexures.

C is a common type of fold in Afghan Turkistan.

D is an overfold.

E is known as a recumbent fold; both *D* and *E* indicate great stresses.

Where strata dip away *from* the same line as the pieces of cloth do in the crests of the wave-like folds into which the layers of cloth were thrown in Expt. 1, Sect. **24**, what is known as an *anticlinal fold* or **anticline** is formed, the line along the arch from which the strata dip being referred to as the **anticlinal axis** (Fig. 176). When, on the other hand, strata dip *towards* the same line, as in the troughs of the experiment, what is called a **syncline** is formed, the corresponding line in this case being called the **synclinal axis** (Fig. 177).

Occasionally it may happen that a folded series of rocks, *i.e.* anticlines and synclines, are incorporated in a major flexure, either synclinal or anticlinal. In the former case the complicated structure is known as a synclinorium and in the latter case as an anticlinorium. It is believed that the Arakan Yomas have, in cross-section, the structure of an anticlinorium, while the valley of the Irawadi covers a synclinorium of Tertiary strata.

Structural folding is common in different places, especially in mountain ranges, which probably owe their origin, in a great degree, to horizontal push or to lateral pressure, similar in kind though enormously greater in degree to the force exerted by the hands in Expt. 1, Sect. **24** (Fig. 179). Folding is only one of the results of forces such as these and, in the case of great thicknesses of strata at or within a slight depth of the earth's surface, must tend to rise up rather than bend down into the solid dense rock below. However, when an inversion of the strata is brought about either by uplift and overturning or by severe over-folding and recumbent folds, there is every probability of the inverted beds being pushed down, and when this occurs folding may also bring about the metamorphic changes dealt with on pp. 277 and 278.

As may be seen in many river sections, or more frequently in railway or road cuttings or often encountered in mining operations, the strata are clearly dislocated by shearing along definite planes at certain places. These planes of dislocation, or **faults**, are sometimes present when no folding is evident; at some places a fold may pass into a fault; and in the case of intensely folded strata it may be found that recumbent folds become sheared along planes which are commonly called **over-thrust** faults or simply **thrust planes.** These are shown in Fig. 178.

Generally, denudation (p. 297) has obliterated effectually all evidence of folding or faulting which may at one time have been apparent at the surface. The continued wasting brought about by atmospheric agencies and the washing away of material effected by running water, not only remove the tops of the anticlines, but also pare down the whole of the folded crust to a more or less dead level. But where any section is laid bare, as in sea cliffs, gorges, or many other such exposed places, any folding or faulting which has occurred becomes apparent. In those regions of folding, such as the Himalaya and its related fold belts, the movements have been so recent that the faults and folds often influence the direction of rivers and ridges. In Tibet it is not uncommon to find that the valleys are in synclines, between anticlinal ridges. In Turkestan, where the streams flow across the folds, each anticlinal has necessitated cutting and the rivers there run in awesome narrow gorges. In Berar the scarp of the Gawilgarh range is due to a strong fault letting down the basaltic lavas to the south into the Purna valley.

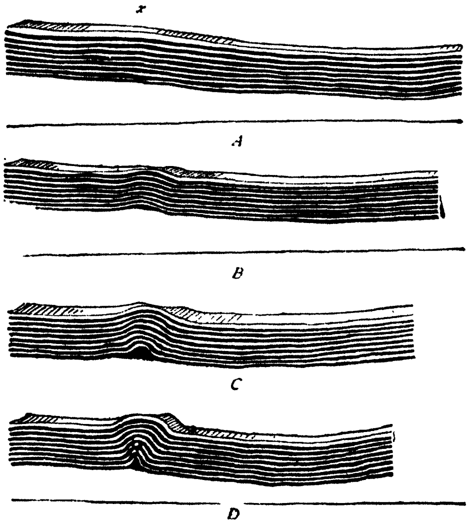

FIG. 179.—Diagrams showing stages in the formation of a folded mountain chain by lateral compression. (Adapted from " An Introduction to Geology ", by Prof. W. B. Scott.)

The movements which have from time to time taken place in the earth's crust, after they actually fracture the strata under enormous pressure, cause the dislocation to increase from what was probably a few feet to several hundred feet. Such fractures or breaks in strata, which are classed together as **faults,** have, in the case of the southern boundary fault of the Raniganj coalfield, *grown* to not less than 10,000 feet vertical throw, while in the Himalayas thrust planes occur over which the strata have travelled horizontally to upwards of 5 miles. The work of denudation is not relaxed all the time the process of faulting is going on and consequently there will probably be no great step occurring at the surface of the crust. Indeed, faults are often only to be recognised by a careful survey of the beds of the district along which they run.

Production of mountain structures.—Mountains are neither all of the same kind nor formed in the same manner. Three of the commonest causes only can be considered here. In the first case **volcanoes** have been instrumental in building up cones of volcanic débris—mud, ashes, pumice and lava—either on the land, as in the case of the defunct Mount Popa in Burma, or in the sea, as in the case of the dormant mass of Barren Island in the Bay of Bengal. In the second case, mountains consist of the remains of hard rocks, either igneous or sedimentary, which have resisted **denudation** to a greater extent than neighbouring strata, and are therefore left projecting above the general level of the district. The gneissic mountain of Parasnath in Bihar is a good example of a **relict** of this type, while the highest peak Dhupgarh, which is capped with basalt, in the sandstone upland of the Pachmarhi hills, affords an illustration of differential erosion. The Western Ghats might be classed in this category of **relict mountains.** So might the scarps known as the Khasi Hills of Assam if there was no suspicion of folding connected with their elevation. They belong to the third type and are classed as **orographic** or true mountain chains because they have axes of folding. The most important mountain ranges, such as those of the Himalaya, Assam, Burma, the Punjab and Baluchistan, have been produced by the **folding** and **over-thrust faulting** set up by slowly acting but enormous pressures in the earth's crust.

As has been explained, the enormous lateral pressures to which the earth's crust has been subjected at various times, probably due to shrinkage from loss of internal heat, produce anticlines and synclines and all the phenomena of over-folding, synclinoria and anticlinoria, as well as over-thrusting. Such pressures are no doubt caused in various ways, but it is easy to understand that the continual transference of immense weights of material from high lands to low plains, which is brought about by rivers, is in itself sufficient to cause immense pressures along lines of weakness. Finally, the persistent influence of the weathering and denuding actions of atmospheric forces caused the upheaved ridge to become sculptured into the characteristic and picturesque forms which we associate with mountain ranges.

The age of mountains.—Considerable information respecting the geological age of any particular folded mountain is afforded by the obvious fact that the uplift must have taken place later than the time of deposition of the youngest strata involved in the upheaval. In this manner it has been found that the loftiest mountain chains now existing—the Alps, Pyrenees, Atlas, Caucasus, Himalayas and Rocky Mountains—were all uplifted in **Tertiary** times (p. 258). The Himalayan uplift probably began in early Eocene times and was active in the Miocene epoch. Indeed it is probable that some of these mountains are still growing.* The Aravalli range, on the other hand, is of very ancient date, and this is true of many other areas such as the uplands of Ireland, the west of Great Britain, Scandinavia, Brittany, the Ardennes, the Appalachians, etc., which are also of ancient date, and must once have been lofty mountains, though they are now greatly worn down by denudation.

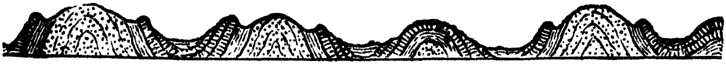

FIG. 180.—Symmetrical folding of the rocks of Swiss Jura.

Earth movements in India.—Several earth movements are known to have occurred in the past history of the Indian region, whereby there have been changes in the distribution of land and sea, accompanied by volcanic eruptions or followed by great alterations in climate, as a result of which new forms of animals and plants have appeared to show the progress of evolution. Movements occurred in the **Archaean** era, before any life appears to have existed on the earth, and we discern only dimly the effects in the worn-down base of what appears to have been a mountain chain on an east-north-east line from the Satpura region towards Bihar, but this is only guesswork and the protaxis of the Satpuras may not be as old as we think. Great movements certainly occurred in the **Purana** era when the Aravallis were a mountain chain of the folded sediments of ancient seas wherein no animals nor plants with preservable parts existed. Dolerite and basaltic intrusions pierced the Cuddapah strata of that period, and the famous " pipe " of Wagra Karur probably marks the position of an ancient volcano. Further movements evidently occurred at the beginning of the **Dravidian** era, when, it is thought, the boundary faults of the Vindhyan formation and those of the Son-Narbada valleys were initiated, but considerable uncertainty exists with regard to these very early movements in the Indian region. The first certain epoch of movement is that at the beginning of the **Aryan** era when the Indian region, Gondwanaland, appears to have been ice-bound, like Greenland of to-day, and submarine volcanoes were active in the Kashmir region.

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* In the case of the Himalayas the movements are indicated by earthquakes due to thrusting. " The exact age of these various Himalayan thrusts is not easy to determine, but, as Mr. Auden has pointed out, they must have taken place over a considerable length of time, some being pre-Pliocene and some post-Pliocene. There is no doubt, however, that the movement has continued up to very recent times. Sir Edwin Pascoe has observed tilted and almost vertical Pleistocene conglomerate, in one place folded into a syncline, at Golra, near Rawalpindi ; while Mr. D. N. Wadia has recorded vertically folded Lower to Middle Pleistocene conglomerate extending for many miles along the north rim of the Soan syncline, the age of which has been determined from their fossil mammals. More recently Mr. H. M. Lahiri has found, at the edge of the foot-hills to the west of Simla, Dagshai (Miocene) beds resting nearly horizontally on the top of the Older Alluvium (Pleistocene), indicating that the thrusting has continued to a very late date." (W. D. West, Pres. Add., Geology Section, Ind. Sci. Congress, Hyderabad, 1937.)

Prolonged movements, again accompanied by submarine eruptions in the Kashmir and N. Afghanistan areas, occurred in the middle of the Gondwana period during **Triassic** and early **Jurassic** times, and the northern Jurassic sea extended into the Arabian Sea on the one hand and from Burma towards the Bay of Bengal on the other. The **Cretaceous** marine transgression, far more extensive than that of the Jurassic sea, was heralded by the outbreak of volcanic activity in the land region of the Rajmahal hills and Assam range. And the final break-up of Gondwanaland, by the subsidence of the land connection between Malabar and Madagascar and the uplift of the sea floor to the north in what is now the Himalayan region, was initiated by the vast outpouring of the Deccan lavas at the beginning of the **Eocene** period. The main **Himalayan** movement, which began in Eocene times, occurred early in the **Miocene** epoch and was evidently rejuvenated in the **Pleistocene** epoch, when volcanic action was active on the Burmese arc and the Persian ranges bordering Baluchistan.

Volcanic activity in India.—As has already been shown there have been several periods in the geological record when volcanoes were in activity in the Indian region, but the evidence relates largely, as far as the Indian peninsula is concerned, with eruptions of lava which poured over the land through great fissures many miles long. The only evidence of a true vent type of volcano appears to be the much denuded core of Wagra Karur in Anantapur, which dates back to early Dravidian times or possibly to the closing epoch of the Purana era. There has certainly been no volcanic activity either in the Peninsula area of India or in the Himalayan region since the

Deccan eruptions of early Eocene times. However, in the mountain arcs which meet the Himalayan range at its eastern and western extremities volcanic action has persisted down to recent times from true volcanoes, such as those of extinct Popa and "smoking" Barren Island, on the one hand, and those of Koh-i-Sultan and Basman Koh, which are in a solfataric stage, on the other. However, all the dykes and sills, lava flows and ash beds (tuffs), and cores of these volcanoes are left standing as indisputable evidence. These remains, long since converted into hard rocks, make very conspicuous features in the topography of the country (Fig. 166). India is not troubled by volcanic activity, but certain areas bordering the junction between the Peninsula and Extra-Peninsula, sometimes partly on one side and often affecting both, have been the scene of an earthquake that has had disastrous effects; slight vibrations in the earth's crust, the result of earthquakes more or less near, are reported nearly every day, from seismological stations situated in the Peninsula.

EXERCISES ON CHAPTER IX

1. What is silt? Where is it generally found, and how is it formed?

2. What evidence is there that certain coasts are rising and others sinking?

3. Describe the "Sandheads", where new land is being laid down by the Hooghly in the sea.

4. Write a brief description of the three recognised types of coral reef and their origin.

5. Describe and account for two examples of destructive and two of constructive work by the sea on the coasts of India.

6. By what processes are materials, deposited on the sea bottom, converted into hard rock?

7. Give four examples of common stratified rocks, and explain the conditions under which each was formed.

8. What are the chief varieties of limestone? How was each formed?

9. In what parts of the world do coral islands occur? Describe the principal stages in the formation of such an island.

10. Give an account of the probable manner of formation of ordinary coal.

11. Explain the terms "Lower Gondwana period", "Lower Gondwana system". Give some account of the Lower Gondwana rocks of the Indian peninsula.

12. Distinguish between metamorphic and igneous rocks. Mention three examples of each, and explain as far as you can how they were formed.

13. Explain, with sketches, the meaning of the terms *outcrop*, *strike*, *dip*, and *unconformity*, as applied to strata.

14. Distinguish between the *dip-slope* and the *scarp-slope* of an escarpment. Explain your answer by a sketch.

15. Define *anticline* and *syncline*. How have these geological features been produced? What is an anticlinorium? Explain it with a sketch.

16. Write a short essay on the formation of orographic mountain chains.

17. Mention one ancient and one recently formed mountain chain. What facts show that they are of different ages?

18. Give sketches of (*a*) an overfold; (*b*) an over-thrust; (*c*) a recumbent fold; and (*d*) a "ramp" valley.

19. What evidence is there of non-active volcanoes in the Indian peninsula or the Himalayas since the Miocene movements?

20. Excluding Barren Island and Narcondam, are there any volcanoes in the Indian Empire which are known to have been active during historical times?

CHAPTER X

DENUDATION: THE ROCK STRUCTURE AND TOPOGRAPHY OF THE INDIAN CONTINENT

25. THE RELATIVE DURABILITY OF ROCKS

1. The action of water on different rocks.—Obtain small pieces, approximately equal in size, of the following rocks: clay, shale, various sandstones, limestones, slate, basalt or dolerite and granite. Put each in turn in a dish under a dripping tap for several hours and observe any differences in the rates at which the rocks are acted on by the water. If possible weigh each piece of rock before the experiment, and afterwards dry each piece in an oven (rejecting any loose particles which have become detached) and weigh again. Make a list of the rocks in order of their durability, so far as this is shown by the experiment.

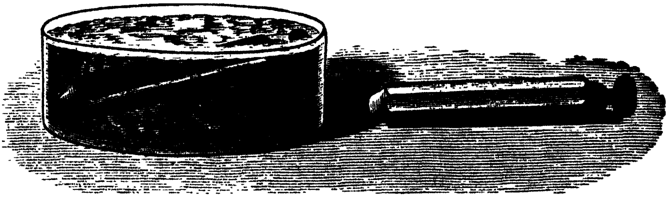

FIG. 181.—Experiment to illustrate expansion of water on freezing.

2. Expansion of water on freezing.—Obtain a small, corked bottle with a narrow neck. Fill it with water and cork tightly, driving the cork in as far as possible. Pass strong fine twine several times round the bottle from top to bottom and over the cork, to keep the latter in. If the string is likely to slip, notches in the cork will prevent it. A small piece of wood similarly notched and put at the bottom of the bottle will prevent the string from slipping there. A " screw-top " mineral-water bottle, filled with water and sealed by screwing in the stopper tightly, may be used instead. Place the bottle in a bowl and cover it with a freezing mixture of ice and salt. Carefully cover the bowl with a duster or cloth until you hear the bottle burst, then take off the covering and examine what has happened. Describe and explain the result of your experiment.

If possible, repeat the experiment with a small cast-iron cylinder (Fig. 181), provided with a stopper which screws in. A louder explosion is heard.

You will understand from these experiments why the water freezes in water pipes and why water-cooled engine cylinders occasionally burst in cold countries in winter. Why is it that the burst pipes or damaged cylinders are not discovered until the thaw sets in?

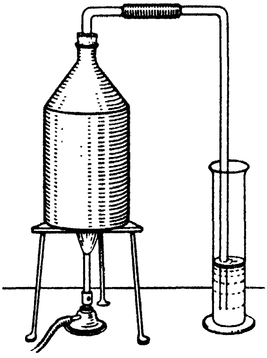

FIG. 182.—Experiment to show that tap water contains dissolved carbon dioxide.

3. The conditions of solubility of calcium carbonate.—(*a*) Put a pinch of precipitated chalk (finely divided calcium carbonate) into a test tube one-quarter full of water, and breathe through a tube dipping in the water so that your breath bubbles through the water. What becomes of the chalk? When the water is clear, heat it until it boils, so as to expel any gases dissolved in it. Describe any change in its appearance.

(*b*) Clear lime water turns milky when exposed to the action of carbon dioxide gas. Breathe through a little clear lime water, by means of a tube, for several minutes, and describe the result. What gas does the experiment show to be present in your breath? How does this explain the behaviour of the chalk in Expt. (*a*)?

(*c*) To find out whether rain or river water (tap water is either rain or river water) contains carbon dioxide in solution, completely fill a gallon can or a large flask with the water, and attach a cork and a delivery tube, which has also been filled with water, dipping the end of the tube into a little clear lime water (Fig. 182). Heat the can. Gas is given off, and as it bubbles through the lime water the liquid is gradually turned milky.

Denudation.—The result of the various activities of water in its different forms, and of air and changing temperature, upon rocks is continually to wear away exposed surfaces and thus to denude or *lay bare* parts of rocks which were previously protected from their attacks. For this reason such agents are generally called *agents of denudation or erosion.*

The sculpturing of rocks by the weather.—In Chapter VII rivers and glaciers were considered as agents by means of which the fragments, derived from the breaking down of rocks, are carried to the sea and there laid down in regular strata. The varying nature of these aqueous deposits, and the processes by which they are changed into compacted rocks and in due course raised above sea level again, to be exposed once more to degradation, were described subsequently. The effect can now be appreciated of the long-continued action of the weather upon rocks of varying composition and physical structure, and the influence this must have in moulding the configuration of the land.

The agents of rock-destruction included under the comprehensive term " weather " are water (and the carbonic acid in it as well as the oxygen mixed in the air) and the diurnal changes in the air temperature which produce the alternation of heat and cold and thus involve the action of frost in cold climates.

Action of water.—**Rain** has a twofold action upon the rocks at the surface of the earth ; it dissolves some of the constituents and also washes away the lighter insoluble ingredients. Obviously its action is more pronounced upon more soluble rocks, such as limestones, than upon less soluble rocks, such as the sandstones, and upon those of friable structure, such as some soft sandstones, than upon those which have been hardened by great pressure or heat, as, for example, some quartzites. The action which rain has in dissolving rocks is increased considerably by the presence in it of gases which it dissolves in its passage through the air. The two gases which are most powerful in this respect are oxygen and carbon dioxide. The dissolved oxygen is particularly active in bringing about chemical changes, known as **oxidation**, which, indirectly causing the decomposition of rocks, facilitates the process of solution. Thus iron sulphide or pyrites, a common substance in some rocks, is converted into iron hydroxide and sulphuric acid is liberated. This acid will react with limestone to form gypsum. The carbon dioxide in rain or percolating water converts certain insoluble carbonates into soluble compounds, in this way causing, amongst other similar results, the solution of calcium carbonate, such as limestone. The amount of calcium carbonate which thus becomes dissolved is very great in some areas, as for example around Cherrapunji. The consequence is that large **caverns** and solution cavities, such as "swallow holes", are carved out of the rock, which is itself composed of calcium carbonate.

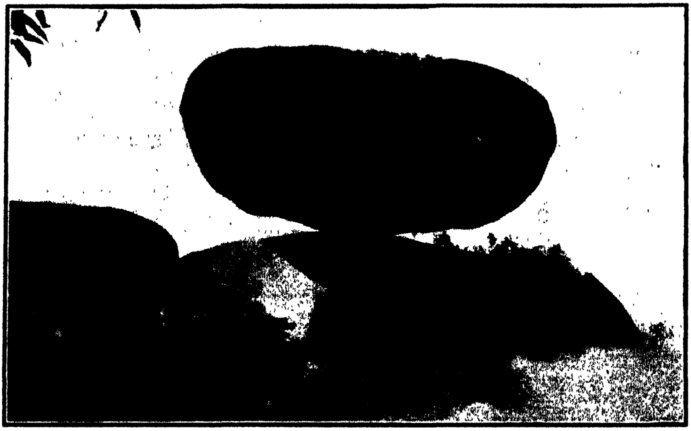

FIG. 183.—Granite "perched block" or "loggan stone", the result of weathering *in situ*, Madan Mahal, near Jabalpur.

The formation of **soils**, and of the layers of decomposed rock occurring immediately beneath these superficial layers, known as **sub-soils**, is partly traceable to the action of rain. Other active influences concerned in their formation are vegetation and certain lowly land animals, chief among which is the earthworm.

An interesting example of the total extent of the rain's activity in earth sculpture is seen in **earth pillars**, like those of some alluvial terraces in the Central Himalayas in Spiti and other places in India and elsewhere. The surface rock in the district where these pillars abound is often a soft clay or shale which underlies a hard layer from under which it is easily worn away. This is why we sometimes find sprinkled over the surface lumps or slabs of loose hard rock on which the rain has little or no action. These serve to protect the soft material underneath them, and the result of the continued action of the rain is to produce pillars of the soft clays, each protected by its own covering of hard rock or a mass of stones, the origin of which it is difficult to fix. The scattered blocks often represent fragmentary remains of a stratum which extended all over the area where they are now abundant, the greater part of it having been removed by the solution and washing away effected by the rain. Thus in England the so-called **grey wethers** common in Wiltshire, which get their name from their likeness at a distance to a flock of sheep, consist of blocks of sandstone and similar rocks. On Salisbury Plain the larger blocks composing the Stonehenge Druidical remains are now known to be of local origin and, unlike some of the smaller stones, not to have been brought from Pembroke in Wales.

Action of frost in breaking up rocks.—When water turns into ice it expands. And when freezing occurs in the crevices or pores of a rock, the expansion forces the confining surfaces apart as effectually as if a wedge had been driven into each crevice. Every additional crack thus opened affords lodgment for more water after the next thaw, so that each frost has an increasingly destructive effect upon the rock in question. The most porous rocks are naturally broken up most quickly, but all rocks in which water can lodge at all are similarly affected in some degree by exposure to alternate freezing and thawing, whether they are masses of large size or the looser clods of earth which we call soil.

It is understood that frost action is only operative as a general phenomenon in cold regions, such as the higher Himalaya, and, as a rule, only during the winter months ; but where rocks are found splintered it cannot be concluded that fresh rock fragments have always been produced by frost action under very cold climatic conditions. Where the climate is subject to great changes of day and night temperatures, considerable expansion and contraction may occur in some rocks, such as some quartzites, causing the mass to fracture and break up into angular fragments. This material falls out and slips down the slope, as scree, and may even creep far out on to the plains, partly due to the continued effects of daily expansion and contraction of the pieces as well as to the effect of occasional heavy rain.

The work of **rivers** and **glaciers** in modifying the surface features of a country is of paramount importance, and has been considered already.

Sculpturing of the land by the ocean.—This sculpturing occurs almost entirely along the coast line of the continents. The ocean currents and movements of the sea other than those on the beach have little, if any, effect in wearing away the land. The work of the *Challenger* Expedition has shown that the floor of the deep parts of the ocean is generally covered with some type of **ooze** (p. 264), a fine muddy deposit, which it is evident would not remain undisturbed were there any perceptible movement of the ocean waters. In those parts of the ocean sufficiently near to the land for sand or other material to be held in suspension, any movement of the water will bring about a certain amount of wearing away of the sea floor, but nothing of importance. Even in the relatively shallow waters of the Bay of Bengal sculpturing by the scour of currents appears rare. For example, according to Colonel R. B. S. Sewell, I.M.S., the deep gulley opposite the mouth of the Haringhata river, known as the Swatch of No Ground, in the sea floor of the Sundarbans, is not due to the scour of seaward currents. He says : " . . . the cañon has been built up, not hollowed out." He adds, however, that "Observations on the deep water temperatures (indicated) that there was a deep current running from the Bay of Bengal to the head of the Swatch. The outflowing river currents must, of necessity, produce an inflowing deep current of oceanic water. . . . If any direct proof of an inflowing current of sea water were required, it is surely to be found in the deposit of Pteropod ooze at the bottom of the Swatch, these delicate organisms having been swept in by the current and killed by the admixture with river water . . ." (*Mem. Asiatic Soc. Bengal*, vol. ix, No. 2, Pt. II, p. 33).

The bulk of the destructive work accomplished by the sea is above low-water mark. Its extent is generally magnified ; the estimates which have been formed of its amount have been exaggerated as a result of dwelling too much upon the activity of the ocean during storms.

The work which is accomplished by the sea is of several kinds. Foremost is the work of erosion effected by the waves, which, dashing against the cliffs hurl any loose material within their reach with a violence which is ordinarily great and during storms stupendous.

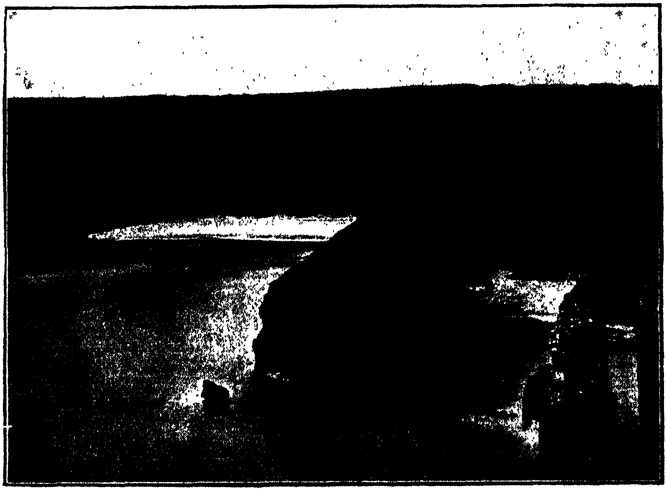

FIG. 184.—Coast scene showing marine denudation, Shrinkle Haven, Manorbier, Pembroke. (Photographed by the Geological Survey of England and Wales.)

The noise of shingle being moved in this manner can be heard at a distance of several miles. Not only are the cliffs broken and worn into stacks, buttresses and needles (Fig. 184), but the stones themselves are ground and worn until they assume the size and smoothness with which all visitors to the western watering-places of Great Britain are familiar. But the breakers alone are often of sufficient force to wrench off huge masses without any aid from loose detritus. Many examples are on record, but it will be sufficient to instance the case of the moving of a block weighing fifty tons by the waves at Barra Head in the Hebrides.

The alternate compression and expansion of air in the crevices of rocks exposed to heavy breakers often dislocate masses of stone far removed above the direct reach of the waves. The hydrostatic pressure of those portions of large waves which enter passages in the cliffs also acts in forcing off huge masses from the rocks. The author has described the action of sea waves on breakwaters in his book, " Engineering Geology ", pp. 241-242 (1935).

FIG. 185.—Ranges of dunes upon the margin of the Colorado Desert (after Mendenhall).

The air as an agent of erosion has been referred to already in connection with the oxidation and solution of rocks. Besides this chemical action the air, when in motion as **wind,** exerts a mechanical force which has far-reaching effects. Loose particles of soil and other materials are constantly blown into rivers ; the sand of the sea-shore is driven hither and thither by the wind, forming, in many places, extensive **" aeolian " deposits,** called **sand dunes,** and—what is more to the point for our immediate purpose—bombarding, wearing down and polishing neighbouring rocks with a force which can be guessed dimly by those who have experienced its effects upon the cheeks.

Dr. W. F. Hume, in his book (" Geology of Egypt ", vol. i, p. 30, 1925), says : " A **Sand Drift** is an accumulation of wind-blown material resting on a steep slope or in valleys . . . over which the sand bearing wind can blow freely. In a **Sand Dune,** on the other hand, the sand is arranged in characteristic forms and is often present in positions exposed to the fullest effects of the wind. . . . There must be a source of supply of the sand and also a wind for its transportation." With these points in mind we may add that a **sand dune** owes its origin to some inequality or obstacle on the surface over which the sand is being blown. A ridge or dune of sand is thus formed, which ultimately may attain a considerable size. Generally dunes slope more gently on the windward side than on the leeward side. Sand is driven along the gentle slope up the dune by the wind, and falls down the steep slope on the other side. In this manner dunes composed of loose sand travel slowly in the direction set by the prevailing wind. Over dry plains and on sea coasts the migration of sand dunes has sometimes very destructive effects, and in many places along the west coast of Europe systematic planting of shrubs and grasses, in order to bind the sand together, has long been practised. Sand dunes are common in western India in Sind, in the Rajputana desert, and in a few coastal tracts.

The purpose of this section has been to emphasise the fact that the rate and extent of denudation vary according to the composition and hardness of the rocks upon which the agents of denudation act. The effect which such varying action in the past has had upon the present topography of our own and, incidentally, upon that of some other countries will next be considered.

26. INDIAN TOPOGRAPHY AS A RESULT OF DENUDATION

1. Mountainous regions of India.—Examine an orographical map of India and adjacent countries,* and note the position of all *land above* 1500 *feet.* Observe that it is nearly all to the north and west of a line reaching from the mouth of the Ganges to the mouths of the Indus. Cover the map with tracing paper, and on it draw the 1500 feet contour line. Now examine Fig. 186, or other geological map. Find on it the outcrops of (*a*) Archaean metamorphic rocks, (*b*) the Deccan volcanic lavas in the Peninsula, and (*c*) the folded Tertiary and other rocks of the Extra-Peninsula.

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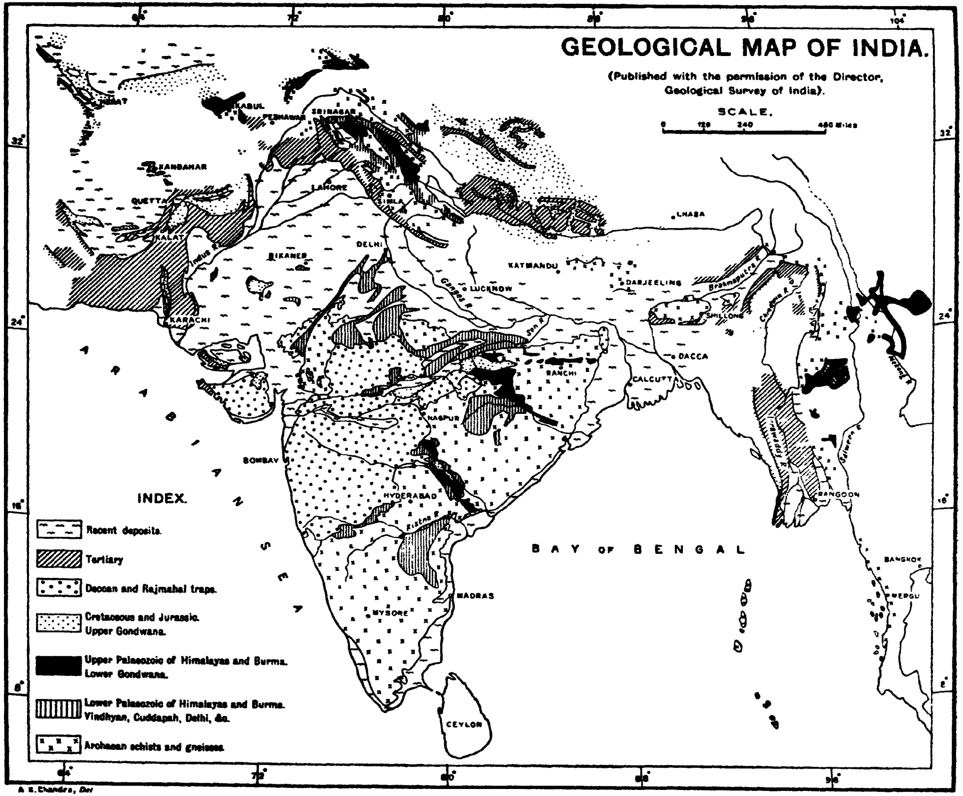
* An excellent coloured map of British India, Plate 4 in the *Atlas of the Imperial Gazetteer of India* of 1909, may be obtained for school or college libraries, with volumes I, II and III of this valuable reference work.

Certain sandstones, slates and limestones of the Puranas occur in large isolated patches in the Peninsula. They include ancient formations, such as the Cuddapahs in the Kistna valley of Madras, and somewhat younger, but still very old, sediments, such as the Vindhyans of Central India. Owing to the great weight of strata which at one time must have covered these unfossiliferous sediments they have been compressed and are therefore hard but still clearly recognisable as sediments. On the other hand the very much younger Tertiary strata, which have been severely folded, have been so greatly squeezed in the mountain ranges as to have become very hard in places and even altered into slates and quartzites and other metamorphic rocks. How does this account for the mountainous character of the regions in which they occur? Notice carefully the positions of the Indian Coal Measures—the Gondwanas.

2. The Indo-Gangetic Plains.—The formations known as Indo-Gangetic alluvium consist largely of soft unconsolidated clays, silts and sands. Find their outspread on a geological map, and then study the districts on an orographical map. What is their range of height above sea level? Is the height greater or less than that of the adjoining districts belonging to other formations? Are the rivers draining the alluvial areas distinguished for their large or for their small size? How do you account for this?

3. The great escarpments and vales.—Observe on the geological map the general parallelism of the Narbada, Son and Assam-Brahmaputra valleys; further (on a detailed map), the manner in which the Archaean rocks of Bihar give place to the Ganges alluvium in Bengal, but come in again east and then south of the Brahmaputra in the Assam range. Now compare the geological with the orographical map, and try to explain the existence of lines of high ground (escarpments—p. 313) of (*a*) the Vindhyan range, the Malwa plateau, and the Aravalli mountains; (*b*) the Satpura highlands, the Western Ghats and the Nilgiri hills; (*c*) the isolated peaks of Parasnath in Bihar, Analmudi in the Palnis of Madras, and Saler in the Dangs of Bombay; (*d*) the valleys of the Wardha-Godavari river, the Kistna, and those of the Son and the Narbada.

4. The topography of Assam.—Observe (Fig. 186) the broad division of the province into five main divisions: (1) the northern border of the eastern Himalaya with its folded and over-thrust strata, trending parallel to the axis of the range; (2) the main Brahmaputra valley, chiefly of recent alluvium. through which in many places the gneissic



A. K. Chandra, Del

FIG. 186.—Simplified Geological Map of India.

floor is visible; (3) the central plateau or Assam range, largely of Archaean gneisses and other metamorphic rocks, which slopes northward more or less gradually to form the floor of the Assam or Brahmaputra valley, but which has a distinct scarp trending east and west at its southern margin, where it overlooks (4) the plains of Sylhet and the Surma valley. Here, bordering the scarp of the Assam range, are folded Tertiary rocks which dip steeply down into the alluvium of the Surma river. Finally, (5) the folded Tertiary strata which form the Patkai, Naga, Barail and Lushai ranges, which sweep southward into Burma as the Arakan Yoma. The folds of the Patkai, Naga and Barail ranges are over-thrust northward, so that the valley of Upper Assam is being pressed down by the vice-like squeeze that is being exerted on it by the pressure of the Himalayas on one side and the Patkai on the other. Thus the Brahmaputra valley between is a fine example of the structure known as a "*ramp valley*". The Assam range (or Shillong plateau) on the other hand is an upward warp, due to the same forces—the Himalayas from the north and the Burma Range to the east.

5. The topography of Burma.—Notice how the "grain" of the country—the ranges and river valleys—trends roughly from north to south. On the west the Arakan Yoma, which consist largely of Tertiary strata with some beds of Cretaceous and Triassic age, are a continuation of the Patkai range and Naga hills and are clearly represented southward in the Andaman and Nicobar islands. In fact, this orographic feature continues through Sumatra and Java to the 120° meridian in a vast festoon. Next follows the Irawadi valley, with its deposits of alluvium and Upper Tertiary sediments, and beyond it the Pegu Yoma, entirely of Tertiary strata. Further eastward lies the valley of the Sittang river, which almost exactly marks a line east of which comes a great area of Palaeozoic rocks including the great Shan plateau and the country bordering the Chinese province of Yunnan. This area is traversed by the Salween and Mekong rivers, and continues southward into Tenasserim and is connected with the Malay peninsula by the isthmus of Kra. Off the west coast of Tenasserim is the Mergui Archipelago and between it and the Andaman islands lies the Andaman sea.

6. Indian river systems in relation to topography.—(*a*) In the manner explained in Expt. 5, Sect **15**, draw the watersheds on a map of India. (*b*) Refer to an orographical map and make a list of (i) rivers which have their sources in the Western Ghats and yet flow into the Bay of Bengal; (ii) rivers which run parallel to any of the escarpments mentioned in

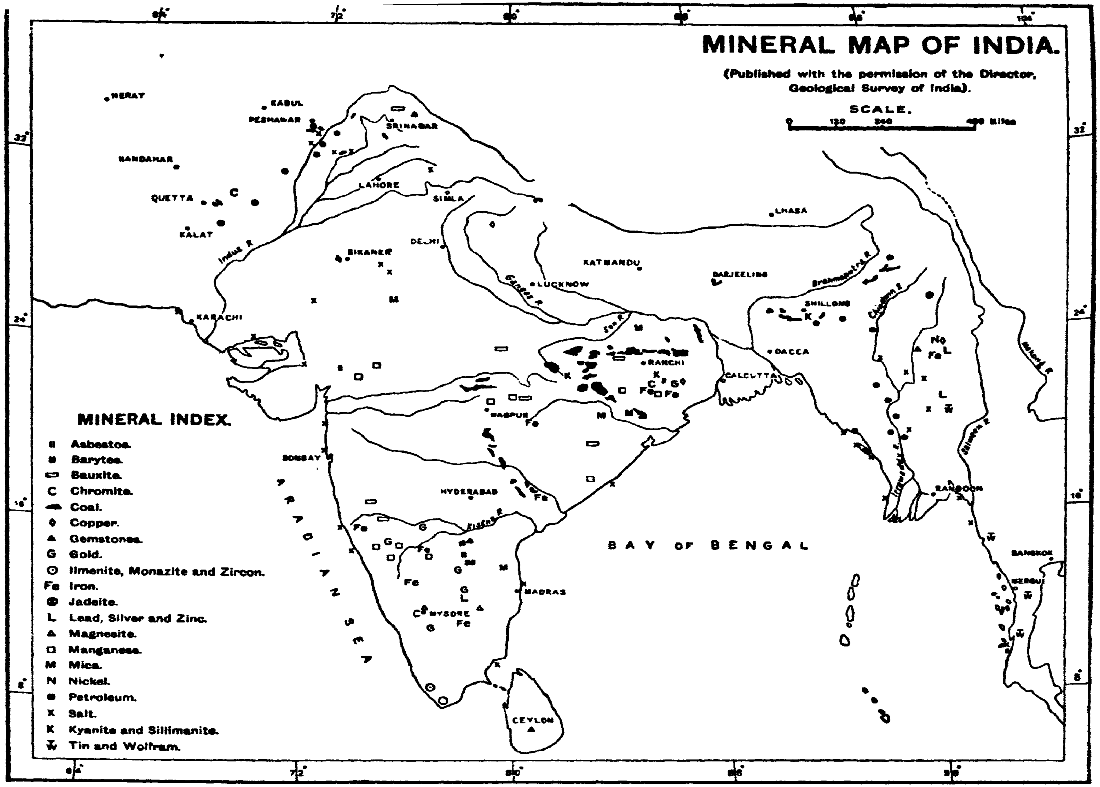


FIG. 187.—Mineral Map of India.

Expt. 3 above; (iii) rivers which cut through the Himalaya range from courses behind these mountains; (iv) rivers which in any other respects take a course not understood easily.

The varied topography of the Indian Empire.—The surface features of the Indian region are so diversified in character that they afford interesting examples of almost all types of land relief. Mountains, plateaux, escarpments, valleys, plains, estuaries and deltas all occur within its boundaries, so that most students in this country can, with very little expense, visit and examine them personally, and can often study on the spot evidences of the stages by which they have assumed their present form. Furthermore, there are several valuable publications dealing with these areas which are issued by Government and are on sale at low prices and so may be readily consulted. Questions relating to military considerations are very clearly dealt with by Major D. H. Cole in his book on " Imperial

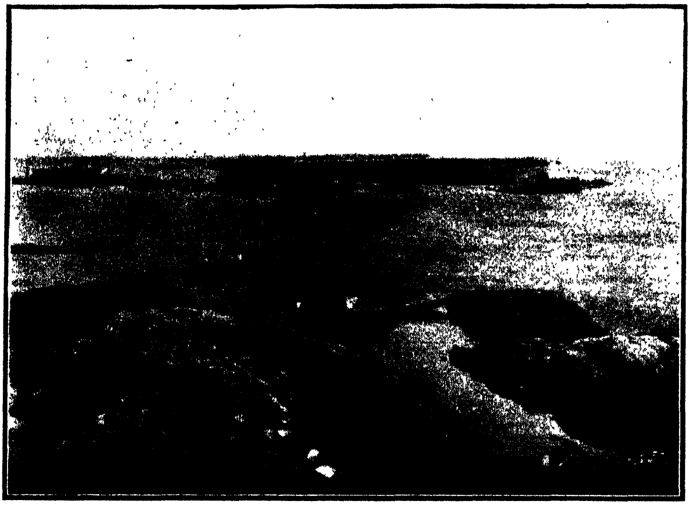


FIG. 188.—View of a sandbank in the Brahmaputra river at Dhubri, where it bends south into Bengal, after traversing the Assam valley. (With the permission of the Director, Geological Survey of India. Photo by C. S. Fox.)

Military Geography" (Sifton, Praed & Co., London), 1935, pages 335-378.

The mountains of India.—Almost all the mountains of India occur to the east, north and west of the belt of alluvium between the valleys of the Indus and the Brahmaputra to the mouth of the Ganges. Indeed, the subsidence of Peninsular India to the extent of some 1500 feet would leave of the rest of India only a few large islands where are now the highest parts of the Deccan—the Western Ghats, the Nilgiris, the Palnis and the Cardoman hills; parts of the Eastern Ghats; the uplands of Central India—the Satpuras, the Malwa plateau and the high lands of Old Chota Nagpur. Most of the Extra-Peninsula ranges—the Yomas of Burma, the Assam hills, the Himalayas and the trans-Indus region—would, however, still remain above sea level, though much cut up by winding inlets. All the deltas of the Ganges and the plains of this river and those of the Indus would become seaways separating the Extra-Peninsula land from a complicated island region to the south, over what is now the Indian Peninsula. Mount Abu in Rajputana, Ginar hill in Kathiawar, and the Eastern Ghats north of the Godavari, would become islands. The Aravallis would be joined to the Malwa plateau by an isthmus, and so would the Assam range to the Naga hills. A splendid gulf would cover what is now the district of Chanda. The Assam valley would be a fine estuary and long tongues of the sea would extend up the valleys of the Salween, Sittang, and particularly the Irawadi. In spite of this subsidence there would still be no large inland lakes in either India or Burma, though those of south-west Afghanistan would become more extensive.

This distribution of high and low land is not difficult to understand when we learn that the hardest rocks are also to be found in most parts of the Peninsula and the Assam range, while the Extra-Peninsular ranges consist of relatively newly upraised strata. Here, as is shown on Fig. 186, are the outcrops of Archaean and metamorphic rocks, as well as of the most ancient (Purana) stratified formations, and the extensive spread of basaltic lavas of the Deccan on the one hand with the folded, overfolded, overthrust Tertiary and older strata of the Himalaya and adjacent ranges on the other. All these rocks are either naturally hard and resistant or have become greatly hardened by the enormous pressure they have undergone by superincumbent loading or by dynamic squeezing, so that the soft sandstones, shales and limestones of some areas have become hard.

Such hard rocks have resisted denudation to an extent which has left them towering above the more easily eroded Lower Gondwana sandstones, shales and coal seams which form the basins of the Son, Damodar and Wardha-Godavari valleys. In the Mahadeo (Pachmarhi) hills, where sandstones also occur, the highest hill, Dhupgarh, is capped by basalt. The isolated peak of Parasnath, which stands nearly 3600 feet above the surrounding country of Bihar, is simply due to the hardness of its rocks compared with those of the area around. Near Mahabaleshwar, in Satara (Bombay), the river Kistna has carved cañons over 2000 feet deep in the horizontal basalt lavas by differential erosion along lines of weakness. Impressive as these examples still are, some of our mountains—for example, the Aravalli range—are now the mere stumps of what they must once have been. Even that prominent ridge the Assam range is an anticlinal feature (a mono-clinal fold), from the original summit of which the later and softer rocks (Cherra sandstones, Sylhet limestones and perhaps other Tertiary as well as Cretaceous beds and Sylhet basaltic lavas) have been removed, exposing the harder and resistent part of the Shillong series, Mylliem granite and even older formations below. Of the Lower Gondwana rocks, the valuable **Coal Measures** are conspicuously marked in the geological maps, and their

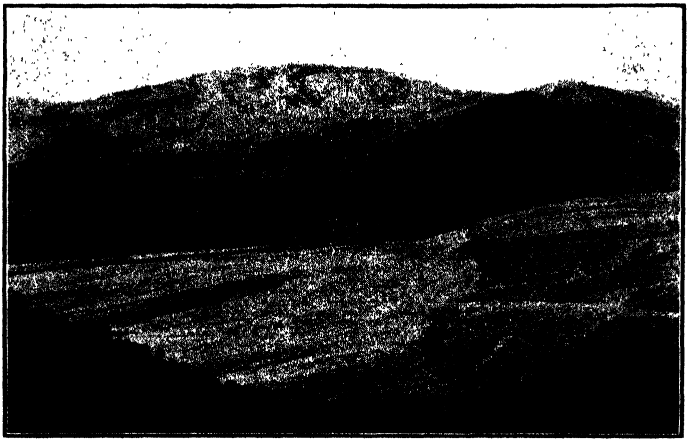


FIG. 189.—A typical river course in the arid region of southern Waziristan. (With the permission of the Director, Geological Survey of India. Photo by A. L. Coulson.)

position in the Indian region should be observed carefully. Reference to an orographic map shows a remarkable coincidence of coalfields and certain river valleys, and emphasises, as scarcely anything else could, the connection between hard and soft rocks and river erosion.

The position of the Indian coalfields must have an important influence in the future on the location of industrial centres and thus on the density of the population. This influence is already noticeable, especially in the case of Great Britain and other countries where the coal supply has played a considerable part in the development of national industries (Chapter XVII).

A great part of India's **mineral wealth**, it is to be noted, occurs in the old rocks. Thus the *mica* of Bihar and Madras come from Archaean rocks, as does also the *gold* of Mysore, while many fine *building stones*, *e.g.* the *roofing slates* of Rewari and Monghyr, the *marble* of Makrana and Sagaing, the *limestones* of Katni and Cuddapah, etc., occur in the Puranas. The enormous deposits of high-grade *iron ore* or haematite in Singhbhum and adjacent States and the *manganese* ore in the Central Provinces are among India's most valuable possessions from the Archaean rocks. The *copper ore* of Singhbhum has been traced to igneous intrusions in the older rocks as have also the *asbestos* and *barytes* occurrences in the Cuddapahs. It is true that the Lower Gondwana coal-seams are newer than those of Europe but they too are of Palaeozoic age and in these measures are also found valuable beds of *fire-clay*. It is not possible to discuss here the *tin* and *wolfram* deposits of Lower Burma, the silver-lead ores of Upper Burma and the minerals of India as a whole (Fig. 187).

The Indo-Gangetic plains.—Separating the rock area of the Indian Peninsula from the Extra-Peninsular region of mountain ranges there is a wide belt of low alluvial country which is so conspicuous a feature of this country as to be recognised as the Indo-Gangetic plains. They extend from the delta of the Indus, up the Indus to the Punjab and, watered by its tributaries—the Jhelum, Chenab, Ravi and Sutlej—cover the watershed north of Delhi and so enter the basin of the Jumna and Ganges and extend to the corner of the Rajmahal hills.

The main Ganges basin is traversed by three important Himalayan tributaries (excluding the little Gumti *via* Lucknow), the Gogra from near the Manasarowar lakes, the Gandak from Katmandu and the Kosi (Arun) from the flanks of Everest. The Teesta, once a tributary from Sikkim, now joins the Jamuna or new Brahmaputra. The alluvial plain extends up the Brahmaputra valley into Upper

Assam and spreads southwards from between the Rajmahal hills and the Garo hills to the Sundarbans (which make the delta of the Ganges in Bengal). The eastern part of the delta belongs partly to the alluvial plains of the Lower Brahmaputra and to the Megna and Surma valley. These plains furnish the richest soil in all India and consequently carry the greatest population per square mile.

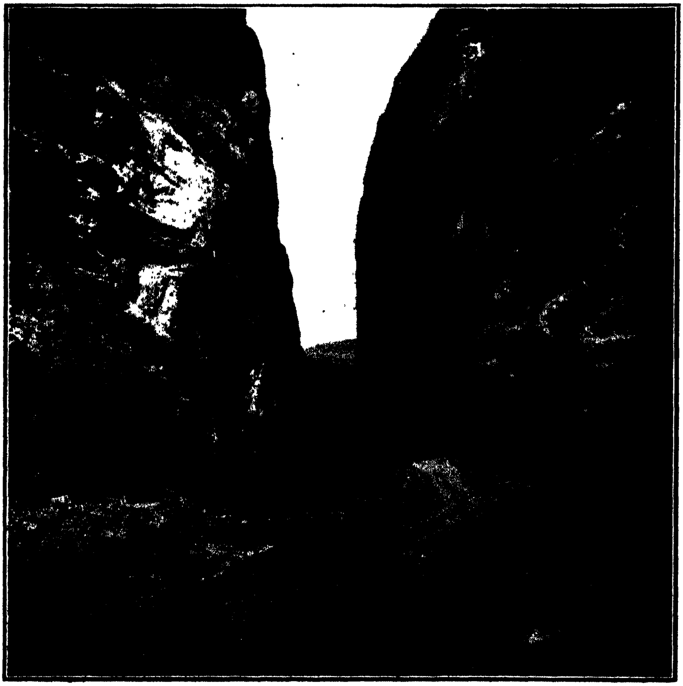


Fig. 190.—A gorge through an anticline of cretaceous limestone near Tashkurgan on the road to Haibak, Afghan Turkestan. (With the permission of Capt. Galloway, British Legation, Kabul.)

In the Surma region and the Ganges delta the country is low lying and often largely under water in the rains. In the Punjab and Sind the plains require irrigation, but as a general rule the Indo-Gangetic plains are of Post-Tertiary, *i.e.* Quaternary deposits of alluvium which have been deposited by the existing rivers in a steady manner on a belt of the earth's surface which appears to be undergoing, at least in places, a slow subsidence. Although this tract boasts no valuable mineral occurrences and its building stone consists of fine *brick clays, sands* and limestone nodules (*kunkur*), it is, agriculturally, one of the richest tracts of India and is the real Hindustan.

The Sind trough of the Indus alluvium is acknowledged to be a tectonic feature trending northwards from the Runn of Cutch in the direction of Quetta. The subsidence in Cutch, after the 1815 earthquake, led to various changes in the topography of this part of Sind, while the recent earthquakes in Baluchistan suggest that elevation is probably in progress in the mountain ranges west of the lower Indus. These phenomena naturally suggest an up-warp to the west and a depression in the Indus valley to the east as the result of compressional forces acting in an east to west direction from Baluchistan towards Rajputana. The basin of the Ganges, from the longitude of Agra to the plains of northern Bengal, also appears to be a specially deep tectonic depression or trough, caused by the overthrusting of the Nepal and Garhwal Himalayas southward against a true up-warp which extends east and west from the Rajmahal hills towards the Malwa plateau. Finally, the Ganges-Brahmaputra delta is another tectonic **down-warp**, produced by the thrust from the Burma, Hill Tippera and Assam range direction westwards towards the Bihar plateau, which has evidently suffered a slow rise or up-warp in relatively recent times. This Ganges delta subsidence is fully established by the depth of fresh water (fluvialile) sedimentation, and is evidently continued seaward as a true trough flanking the Arakan Yoma-Andaman-Sumatra axis of mountain folding.

Escarpment and vales.—A very large part of the drainage of the Indian Peninsula discharges into the Bay of Bengal. This is due to the eastward tilt of the Deccan from its scarp at the Western Ghats which overlook the Arabian Sea. This great western scarp or ghats, known as the Sahyadri range, is not a true orographic feature of folded rocks, nor is it an ancient line of cliffs which have been formed by the action of the sea waves. It is due to great dislocations or faults, whereby part of the land west of longitude 72° E. has been depressed far beneath the waters of the Arabian Sea ; part, from longitude 72° E. to the Konkan, is, in places, still at sea level ; and the eastern part, *i.e.* the Western Ghats, has suffered elevation. In fact the Peninsular of India is now known to be traversed by several great faults, which have broken it into great blocks and where relative up or down movement has occurred on opposite sides of a fault plane there is now found an **escarpment** or scarp, often spoken of as a *ghat,* of which the best example is that of the Western Ghats, but the Vindhyan range, which is the southern escarpment of the Malwa plateau, is due to similar causes. The Gawilgarh range in Berar is a further example ; this forms the northern scarp of the Tapti valley and is due to an important fault which trends from near Bhusawal to beyond Ellichpur.

The valley of the Narbada river, from near Jabalpur downstream, appears to be largely determined by faults on the southern side especially where the upward movement has been south of the plains. The escarpment of the Vindhyans is also thought to have been caused by faulting, but as the Vindhyans are clearly more and more disturbed by folding as they are traced southwards, south-westwards and westwards, it is certain that simple faulting will not provide a full explanation of their escarpment in these directions, and differential erosion must play a considerable part in the formation of the northern edge of the Narbada valley. Faulting and differential erosion play the chief parts in the formation of the Wardha-Godavari Mahanadi, Son and Damodar valleys and, but for the boundary faults having dropped the Lower Gondwana coal measures into deep rifts in the gneissic blocks of the Peninsula, differential erosion would have completely removed the valuable coal seams which are to play so great a part in the future industrial development of India.

True differential erosion, evidently unassisted by faulting but due to the general uprise of the southern portion of the Indian Peninsula, has been almost entirely responsible for the topography of the Nilgiris, Palnis, Cardoman hills and the entire Eastern Ghat ranges. The most famous feature in this region is the Palghat **gap** * which is the only break in the whole extent of the escarpment of the Western Ghats, from the Tapti to Cape Comorin, and through it a fairly large river has cut its way westwards to the Arabian Sea. A study of a geological map of India also shows that the basins of the Cauvery, Penner and Kistna rivers, with their tributaries, have been carved out by river action alone as there is little evidence of great faults of relatively recent origin. The occasional earth tremors that are sometimes felt in the Madras Carnatic probably occur as earthquakes in the Bay of Bengal, west of the Andaman islands, and are probably caused by the dynamic forces still operative on the axial line which passes through the Andamans from Sumatra to the Arakan Yoma.

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* *Gaps* are placed where a river has cut through an escarpment or ridge and still flows through this cutting, but when a river ultimately leaves this course for another, the opening of the old river channel is usually referred to as a *dry gap*.

Thus in a sense the Bay of Bengal is a tectonic depression corresponding to that of the Arabian Sea west of the Laccadives and between which the southern part of the Peninsula is slowly rising or being pushed up as a " warp "

The topography of Assam.—The Brahmaputra valley of Upper Assam has the peculiarity of being bordered both to the north and south by mountain ranges in which the strata have been folded, overfolded and overthrust from opposite sides towards each other, due to immense compressional forces evidently acting almost horizontally. The result has been that the Archaean rocks of the valley floor have been squeezed as in a great vice and depressed; so this part of the Assam valley is a tectonic feature and an interesting and clear example of a " *ramp valley* ". However, as the Patkai range passes into the Naga hills it swings south-west and southward and so diverges from parallelism with the eastern Himalayas, but the squeeze has evidently been maintained, for in the Barail range a great line of overthrust faulting—the Haflong fault—has been recognised. The Assam range and the Surma valley are also intimately related to, and caused by, these forces of compression from the Himalayas to the north and the Naga and Manipur hills to the east.

The result has been that though the Himalayan range is being overthrust in the Brahmaputra valley on to the gneissic Archaean rocks, the thrust has caused these rocks to bend upward in a " **warp** ", mono-clinal fold, with an east to west axis, and so produce the Assam range. This uprise or mono-clinal (anticlinal) fold has a corresponding down-warp or depression to the south, which is being filled with the débris of the elevated land around and which we recognise as the Sylhet plains of the Surma valley. Complicated as this structure is, it is even more so in detail, but the dynamic movements which are still operative, as evidenced by the frequency of earthquakes in the Assam region, together with the character of the rocks or strata involved, fully explain the curious topography of Assam—(1) the Eastern or Assam Himalayas to the north; (2) the Brahmaputra or Upper Assam valley; (3) the Assam range, including the Garo, Khasi, Jaintia and Mikir hills; (4) the Surma valley; and (5) the meridional ranges of Manipur, Lushai and Tippera to the east and south.

The topography of Burma.—The mountain ranges of folded and twisted and frequently metamorphised sediments which separate Assam from Burma are often so steep and so densely afforested that communication across them is conducted with great difficulty and forms a stumbling block to railway engineering. In Burma, however, the valleys of the Chindwin and Upper Irawadi are delightful and well cultivated and offer inducements for commercial enterprise. The source of the Irawadi has long been an interesting problem, as it begins in that hydrographic centre of Eastern Tibet where several important rivers have their source and the region is imperfectly known. Here the Hoang Ho, the Yangtsi and the Mekong take their rise, and from here also comes the Giama Nu Chu which flows into Burma and connects with the Salween, but the question has been raised as to whether it might not be the upper waters of the Nmai Kha, an important tributary of the Irawadi above Myitkyina. During recent years surveys from Upper Assam, through the so-called Hukawng valley, have shown the possibility of a suitable railway alignment between Margherita and Mogaung. With the great coal deposits in the Namchik section of this alignment and the economic potentialities of Upper Burma, there is a probability of railway communication between Upper Assam and Upper Burma.

In Burma the features of the land are simple and closely connected with the geological structure of the country. The Arakan Yoma of folded Tertiary and Secondary rocks forms the coastal and western border trending southward. It was probably once a continuous mountain chain, perhaps to Sumatra, but only the Andamans and Nicobars now show above sea level. Next follows the valley of the Chindwin and the Lower Irawadi, with folded Tertiary and Secondary strata, between the Chindwin and the Upper Irawadi, and the Pegu Yoma between the Lower Irawadi and the Sittang river. East of the line of the Sittang and Upper Irawadi comes the great Palaeozoic Shan Plateau of Burma, which is continued southwards into Tenasserim and so by the isthmus of Kra into the Malay Peninsula.

These orographic features are quite plain and are traceable to earth movements not yet dormant. The compression causing this north and south system of hills and valleys is acting in an east to west direction but with most interesting effects. The Arakan Yoma appears to have the structure of an anticlinorium, while that of the Pegu Yoma is believed to be that of a synclinorium. The older rocks of the Shan Plateau are thought to be an over-thrust movement eastwards along the line of the Sittang and Upper Irawadi. This line has lately come under notice because of the number of earthquakes which appear to have originated in its vicinity. The line of dormant volcanoes from Java and Sumatra to Narcondam and Barren Island also seems to have continued between the Pegu and Arakan Yoma to the extinct volcanoes of Hawshuenshan and Puppa Doung (Mount Popa.)

Indian river-systems in relation to topography.—The peculiar routes by which the Indus and the Brahmaputra rivers flow from their sources to the sea are in themselves sufficient evidence that the surface-relief of our country has undergone a great change since the Himalayas became " dry land ". Most of our rivers are normal in taking a more or less direct course from source to mouth. There is nothing very strange, for example, in the general paths followed by the streams which have their sources on the eastern slopes of the Western Ghats, which indeed form the western part of the line—called the **watershed**—dividing the Peninsular rivers flowing into the Bay of Bengal from those flowing into the Arabian Sea. Again, in the case of Central India an " axis of elevation " can be traced from the Rajmahal hills in a westward direction through Bihar to Indore and the Gulf of Cambay ; this, it is supposed, has been denuded to an extent of thousands of feet since it was first formed, but the watershed is still sufficiently well marked to account for the flow towards the Ganges plain of the streams rising on its northern slope, and towards the Bay of Bengal of those rising on its south-eastern side. Further, the flow of such rivers as the Narbada and the Tapti along the " longitudinal " valleys which they have excavated in formations lying in fault rifts or troughs between harder rocks, is what might have been expected.

But when we consider such rivers as the Godavari, the Bhima, the Kistna, the Tungabhadra, the Vedavati, and the Cauvery, all of which rise close to the Arabian Sea coast on the edge of the Western Ghats but flow inland, ultimately to reach the Bay of Bengal at a considerable distance from their source, we are compelled to assume that the Deccan topography has undergone a marked change since these rivers began their career. When, however, we turn to study the courses of the Indus, Sutlej and Brahmaputra—all of which begin in the region of the sacred Kailas mountain near the Manasarowar lakes and flow away from each other behind the line of snowy peaks of the Himalayan range—we are confronted by problems which must involve, in some cases at least, examples of **river capture** (p. 319).

It is believed that the ancient Tsanpo or Upper Brahmaputra was diverted into India through the Assam Himalaya by an active younger river, which flowed into the Bay of Bengal, cutting back its head-waters and so capturing the drainage of the Tsanpo. Dr. A. M. Heron, after his work in Tibet, has stated that in some distant future the Arun may capture the upper waters of the Tsanpo and so rob the Brahmaputra of some of its drainage. At an earlier period the Brahmaputra of Assam appears to have had its course through the Cachar hills into the present Surma valley, but warping across its channel has forced the river round the Garo hills. Even then it turned eastward into the Surma valley (in Mymensingh) and it is only very recently, due to subsidence in the Ganges deltaic area, that it has taken the course of the Jamuna, west of Dacca, and the same subsidence has caused the Teesta to change its course and join the Jamuna after previously having been a tributary of the Ganges.

Perhaps the most interesting of all Indian rivers, from the point of view of topographic changes, is the Ganges which begins as the Bhagirathi in the ice cave (Gai mukh) of the Gangotri glacier on the northern flanks of the ridge joining the peaks of Kedarnath and Badrinath beyond the borders of Garhwal.* This river emerges from the hills at Lachmanjhula and passes out into the Indo-Gangetic plains at Hardwar. It appears to have maintained its present channel fairly well up to the northern spurs of the Rajmahal hills, where it turns south to pass the ancient ruins which mark the position of the great city of Gaur in Malda district. It is a little below this position that the Ganges throws off its first distributary and so begins its delta, which we take at the line joining Gaur with Dhubri.

According to historical evidence this first distributary—still known as the Bhagirathi—was the main Ganga barely 600 years ago and flowed, as it does now, due south to the mouth of the Hooghly to Gunga Sagar (Saugor island), practically along the course of the existing Hooghly river. The main river appears frequently to have changed its course below Gaur during the last 600 years, having successively discharged into the sea from what are now the mouths of the Matla, the Kalinai, the Kabadah and the Haringhata, and thus eventually on a south-east course to the eastern side of the Sundarbans which it has built up. About 100 years ago, when the Brahmaputra deserted its old course and took that of the Jamuna, it was joined by the Ganges near Goalundo. The confluence of these rivers has since been subject to change but their combined waters, as the Padma, discharged into the old Brahmaputra, or Meghna, and through this old estuary reach the Bay of Bengal between the backwaters of Backerganj and the open channels south of Noakhali.

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* The popular belief is that the Alaknanda, leading to the hot springs of Badrinath, is the true *Ganga* ; however, there is no doubt of that part of the river below Devipryag where the Bhagirathi and the Alaknanda join and become the Ganges or Ganga.

Except for certain hypothetical cases of **river capture,** such as the probable deflection of the Tsanpo by the Brahmaputra into India and a great change in the watershed between India and Tibet as a consequence, there are not many established instances of the alteration of watersheds in India. It has been suggested that at the close of the Tertiary era (Siwalik times) a great river having its source in Upper Assam flowed along the base of the Himalaya to the Punjab and so round by the Indus valley to the Arabian Sea of that period. Young rivers cutting back from the Bay of Bengal, presumably the Bhagirathi and Brahmaputra, have deflected the older Siwalik river, or Indo-Brahm, southwards and produced the modern Ganges and Brahmaputra rivers. However interesting this explanation may be of the birth of the Ganges its disagreement with many facts can be easily proved, such as the presence of an estuary in Upper Assam close to the supposed source of the Siwalik river. But there seems to be little doubt that the present Jumna river, from about Karnal, north of Delhi, and the existing Ghaggar, from near Nahan east of Ambala, both flowed westwards to combine about Suratgarh in north Bikaner and continued as the Hakra through Bahawalpur to join the Indus. The dry bed of the Hakra or Lower Ghaggar is still recognisable and is shown on most maps of North Rajputana or the Southern Punjab.

With the steady depression of the main valley of the Ganges the Jumna has become a tributary of the sacred Ganga, but the Ghaggar rivers of Nahan and Ambala still flow south-west and eventually lose their waters on the borders of Bikaner about Bhatnair (Hammangarh). Perhaps what was the old Jumna but is now the Ghaggar flows from Karnal through Jind and Hissar and loses itself in Bikaner about Bhadra. These modern streams show that no great change of watershed has taken place in this region since the Jumna was captured by the Ganges (if it was ever really an Indus tributary). If the tectonic depression of the Indus is in active formation, and an up-warp is in progress along a line from the Aravalli range to west of Delhi, there would appear to be potentialities for the rejuvenation of the Ghaggar and the recapture of the Jumna by the Indus, if the main Ganges trough is not equally or more actively undergoing depression.

River valleys as means of communication.—A glance at a map of India showing the railways will reveal the extent to which the railroad alignments follow river valleys. Bombay is reached from the Deccan down the difficult Bor Ghat from Poona and Thal Ghat from Manmad by the Great Indian Peninsular Railway, and this engineering feat has added greatly to the prosperity of Bombay. Access to Marmugao in Goa from Londa in the Deccan by the South Mahratta Railway has also been difficult and expensive, whereas no serious difficulties were encountered in carrying the Madras Railway from Coimbatore (Podanur) to Calicut and Cochin through the Palghat gap (Fig. 24). " Dry " gaps, as well as the valleys through which rivers still flow, form a valuable means of communication between regions separated topographically by high land. A well-known example is the Bagiari gap, through which the Khyber Railway enters the hills from Jamrud and Peshawar on its way to the Khyber valley and the Afghan Frontier (Fig. 39). The original alignment was via Michni and up the cliff-sided valley of the Kabul river to Loe Shilman, but this railroad was abandoned and the rails removed and for some years, the line of cuttings and tunnels, marked " The Broken Road ". A motorable road is now available on this line.

The Nizam's Guaranteed Railway, which taps the Singareni coalfield on its way to join the Madras Railway, takes advantage of the Kistna river gap through the Eastern Ghats near Bezwada, where the junction is effected. The Great Indian Peninsular Railway alignments from Bhusawal into the Narbada and Wardha valleys have followed the Tapti and Purna valleys respectively, and then crossed the low divides at Khandwa and Badnera for Itarsi and Nagpur.

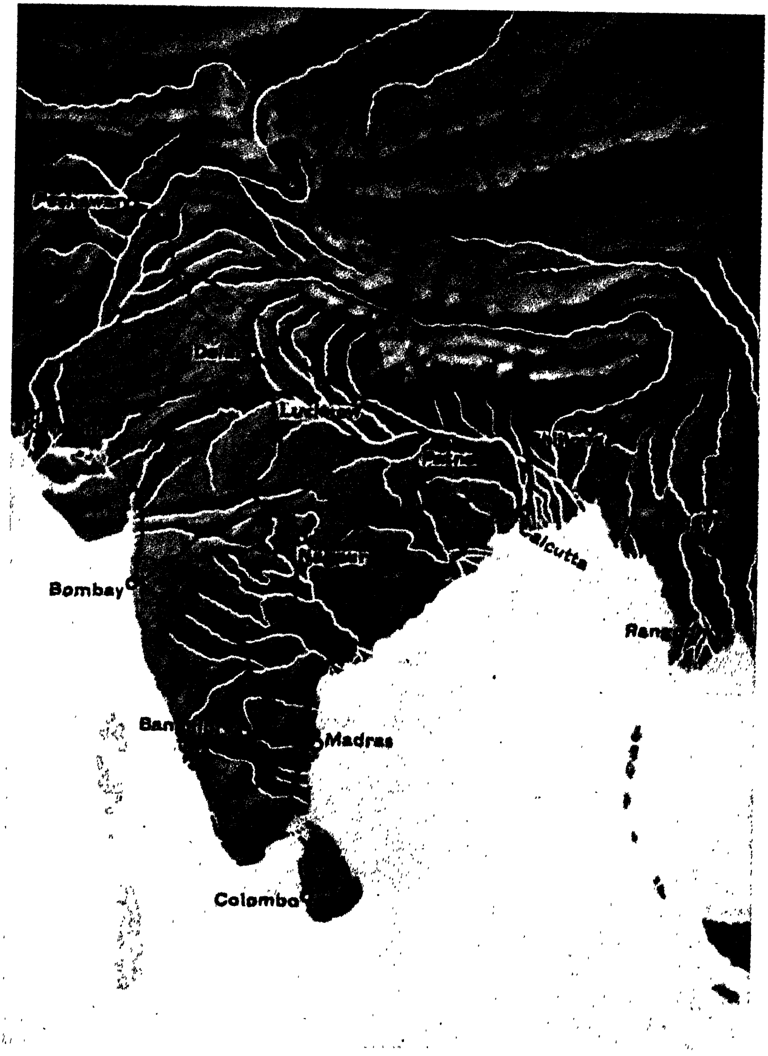

FIG. 191.—Map of India, showing rivers, mountains and chief railways.

It is instructive to follow, on an orographical map, the North-Western Railway lines to the Afghan frontier, and observe how and to what extent they respectively utilise river valleys to evade the difficulties of the mountainous districts west of the Indus. After the Attock bridge over the Indus the line follows the Kabul river to Nowshera, where a branch line goes up a tributary valley to Mardan, the headquarters of the Frontier Force (the Corps of Guides), and so to Dargai aiming for Malakand and the Swat, Dir and Chitral areas, while the other branch goes to Peshawar and on to the Afghan frontier through the Khyber Pass. The Kohat alignment crosses the Indus by the Khushalgarh bridge up the Kohat valley, then crosses the Hangu gap and enters the Kurram valley on its way to Thal and Parachinar for Kabul through the Peiwar Kotal. The Bannu branch crosses the Indus at Kalabagh and enters the hills at the Lower Kurram gap between Isa Khel and Lakki, where the line bifurcates—one branch going to Bannu for communication with Miram Shal in North Waziristan by the Tochi valley and the other south over Pezu saddle to Manzai (opposite Jandola) in South Waziristan to reach the Gomal valley.

Even more markedly dependent on river valleys are the north-western railway lines diverging from Quetta. The original Sind-Pishin alignment was by way of the Upper Nari valley in which lies the unstable Mud Gorge, the famous Chappar rift, and the Khost coal mines, through Harnai to Sibi in the plains, but owing to slips in the Mud Gorge it was found advisable to construct the Bolan Pass line from Sibi up the Bolan river through the pass to Mach and Spezand and so to Quetta from the south. The branch line for Kila Abdulla and Chaman, opening the way to Kandahar, leaves the Sind-Pishin line at Boston, and the line for Hindubagh takes off from Khanai up an easy divide at Toraghburgi to enter the Zhob valley. Finally, the line for Mushki and Dusdap (in Persia) leaves the Bolan branch at Spezand. In all these cases, except that of the Khojak tunnel between Kila Abdulla and Chaman, through the Khwaja Amran range, the alignments have been carefully chosen along river valleys and over low watersheds or divides.

It need scarcely be added that most of these routes were used as highways of communication long before the laying of the railroads.

Lakes.—Hollows in the surface of the land which have become filled with water are known as **lakes.** They vary in size from that of Lake Superior, of about the same area as Kathiawar, to tiny ponds, even smaller than Naini Tal; but India possesses few lakes and none of any considerable size. Lakes may be divided into classes, either according to their composition into fresh or salt, or according to the way in which the depression in which their waters have accumulated has been formed. No classification of lakes is altogether satisfactory, and there is much diversity of opinion on the subject. Some authorities, for instance, divide lakes into classes depending upon their situation, others regard the fact of lakes having streams running in or out of them, or both, as being the important matter; but whatever system of classification is adopted, it is of importance that the student should know some of the causes which have helped in the formation of lakes.

The suspended materials brought continuously into many lakes by rivers flowing into them tend gradually to silt them up and obliterate them. Judged in connection with rivers, lakes may be regarded as **temporary modifications of the rivers.** The heads of all the Kumaon lakes and of most others, such as Loktak lake in Manipur and Wular lake in Kashmir, show flat plains, formed of deposits laid down by the streams which are flowing into them and gradually filling them up (p. 171). Because of this tendency to their obliteration, lakes in general must be of recent geological origin.

As a typical method of classifying lakes, one depending upon the nature and origin of their basins may be described:

1. *Lakes of which the basins have been formed by underground movements of the earth's crust.* It has been learnt already that movements of this kind have had important effects in the production of mountain ranges, in producing sinking areas or tectonic troughs, in causing volcanic eruptions and earthquake disturbances, and in bringing about changes of level in the earth's surface. These great earth-movements have assisted in the formation of many of the great lakes of the world, such as those in the Great Rift valleys of Africa—Tanganyika, Nyasa, Rudolf, etc., associated with which are many dormant volcanoes, in the craters of which lakes are now occasionally found. The curious cauldron-like hollow in which lie the waters of Lonar lake in the Deccan has been ascribed to an "explosion crater" and thus classed as a **crater lake,** but by others

who have studied this remarkable hollow, it is believed to be due to subsidence. The Runn of Cutch is almost a lake and is caused partly by subsidence resulting from seismic phenomena which accompanied the earthquake of 1815 in that region.

It was certainly a slow subsidence which was responsible for the low marshy plains of Sylhet and Mymensingh with their innumerable **bils** and **jhils** which, during the rains, become almost a freshwater sea. Many of the small hollows or " sink-holes ", which occasionally hold little lakes in the limestone tracts of the Khasi and Jaintia hills of Assam and on the Shan Plateau of Burma, owe their origin to the collapse of the surface caused by the removal of the limestone by the solvent action of underground waters. The same phenomena is, of course, more active where beds of rocks salt underlie the surface formations, as at Pidh near Dandot in the Punjab Salt Range.

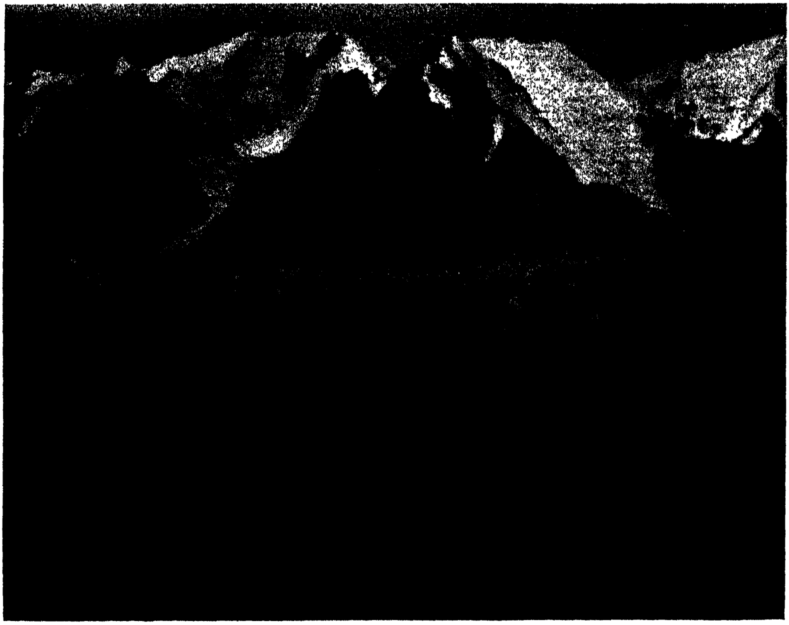

FIG. 192.—Lake formed by the ice dam of the Chong Kumdan glacier slipping across the Shyok valley. (With the permission of the *Himalayan Journal.*)

2. *Lakes caused by irregularities in the deposition of accumulations on the earth's surface.* Prior to the elevation of the land, during the disappearance of the great ice sheet, which in the Pleistocene glacial period of geological time covered the northern parts of Europe and America, many small and shallow lakes and tarns of the lowlands of the North of England, of Scotland, and of Ireland, were made by water filling hollows between the glacial moraines. These lakes are enclosed by mounds and ridges of " drift " clay and gravel deposited by glaciers. Lakes of this type are usually small and not uncommonly associated with some of the Himalayan glaciers of the day, as in the Chombu glacier in Sikkim (Fig. 133).

3. *Lakes caused by the accumulation of barriers across river valleys, and the consequent ponding back of the water.* Such a barrier may result from a " land-slip " across a deep valley so that a lake is formed which, after filling, may discharge a dangerous flood down the valley, as in the case of the Ganges floods of 1894 from Gohna lake, British Garhwal, due to the slip of 1893. Deltaic lakes are often formed by the enclosing of a hollow between two out-growing passages of a delta, or of two deltas, as in the case of Kolar lake near Ellore, due to the growth of the Godavari and Kistna deltas. Chilka lake is an example of a lagoon formed by deposits of sand carried up the Orissa coast by sea currents in the Bay of Bengal; and the backwaters of Cochin and Travancore are due to similar causes.

Lake Tana in Abyssinia (Ethiopia) was formed by a relatively recent lava flow across the valley of the Blue Nile (Bahr-el-abiad) near its source—the present outfall of this great lake. The passage of a glacier transversely across a valley, as in the case of the Chong Kumdan glacier of the Shyok, a tributary of the Indus, may also produce a great lake. Such a lake however, is liable to cause disastrous floods down the valley when the ice dam bursts (Fig. 192).

4. *Lakes resulting from erosion.* This erosion has been brought about either by the prolonged action of glacier ice, or by the unequal denudation resulting from the action of the weathering influences described in Section 25. Wales, Scotland, Switzerland, Scandinavia and North America all present many examples of what are called " Alpine " and " sub-Alpine " lakes, and all of these countries in an increasing degree have been subjected to glacial action. But lake basins are eroded sometimes by agencies other than ice. Rain, wind, frost, and so on, may cause some rocks to break up at a more rapid rate than others in the neighbourhood, and when the débris formed has been removed a sufficient depression results to lead to the formation of a lake basin.

Coast-line features of India.—It has been seen that marine denudation has played only a minor part in the development of the present coast lines of the Indian Peninsula and Burma. Nevertheless, certain well-marked features of the coast, both of India and Burma, and the islands of the Andaman sea, are to be attributed to the sculpturing of the land by the ocean. Naturally, the extent of this erosion will depend as well on the softness of the rocks constituting the cliffs as on the violence of the seas during the south-west and north-east monsoons. It would be to the western coasts of the Peninsula, Tenasserim, and some parts of Madras and Akyab (Fig. 186) that one would naturally look for the best examples of this kind of work, for it is there that the rocks are exposed to the full fury of the Arabian Sea and the Bay of Bengal.

EXERCISES ON CHAPTER X

1. If the sea level rose 1500 feet all the lowland parts of India would be submerged. Describe shortly, or show by a sketch, what the map of India would then be like.

2. Describe the result of submerging the Indian Peninsula to a depth of 1500 feet.

3. In some parts of India and Burma the surface consists of limestone. State the positions of some of these parts, and point out any peculiar features about the rivers which flow over them.

4. Explain the terms watershed and river basin, and give examples from the Deccan and Central India.

5. Describe the water parting (watershed) of the Brahmaputra basin, excluding the Meghna, and point out where it runs along ridges.

6. How would you describe the distribution of the basaltic lavas and the Deccan escarpments over western India? What effects on the river may be traced to this distribution?

7. Describe the conformation of the highlands of the central Indian region which divide the rivers flowing into the Arabian Sea, the Bay of Bengal, and the Ganges valley.

8. Discuss carefully the position and the character of the Aravalli range of Rajputana, showing its past and present importance.

9. " The Indian Empire should be divided into its natural regions as determined by the relief of the land, and each region should be treated separately." Draw up a short scheme of lessons based on this statement.

10. Describe the physical features of Burma *north* of a line drawn from the Alguada reef to Mu-ga-dok hill on the Siam border, and illustrate your answer by means of a sketch map.

11. Describe (*a*) the relief, (*b*) the river system, (*c*) the positions of the towns, of the region comprising the Assam range and the Surma basin of Assam.

12. Describe carefully the original *loop line of the East Indian Railway* route from Calcutta to Allahabad, showing clearly how it was influenced by the relief.

13. Describe the distribution of six Indian lakes, and show how each of them was formed.

14. Contrast the Himalaya with the Indo-Gangetic Plain. Consider both the physical conditions and the geological movements, and give detailed information as far as you can.

15. What river basins are continguous to the basin of the Kistna? Describe the character and position of the watershed in each case.

16. Describe carefully the relief of the North-West Frontier Province. Point out how it has influenced the important railway routes to the Indian frontier.

17. Name the coalfields of the Indian Peninsula, and in the case of two of them explain their relation to the geological structure.

18. What types of land-forms are illustrated by any *three* of the following: the Assam range, the Aravallis, the Satpuras, the Western Ghats and the Palghat Gap?

19. The rivers of India may be grouped into four main systems. Indicate what physical features constitute the water partings, and compare the configuration and industries of the regions thus drained.

20. Indicate the important differences between the conformation of the hills of the Western Ghats and those of the Eastern Ghats.

21. Describe the structure and configuration of India south-east of a line passing through Madras, Mysore and Mahe.

22. Describe briefly the general arrangement of the drainage systems of the marsh-lands of Sylhet and Mymensingh. Give instances of striking exceptions to this system and try to explain them.

23. Describe the characteristic features of a cave in a limestone region, and explain how such caves are formed.

24. Describe typical landscapes in the Rajputana desert, the Pachmarhi hills, the plains of Lucknow, Eastern Bengal and the Shan Plateau. Account for the differences noticed.

25. Describe carefully four ways in which lake basins have been formed.

26. Describe the process of marine erosion. In what parts of the Indian peninsula is the coast line being slowly added to and why?

27. What do you understand by " river capture "? How may it be brought about? Give any examples you may know.

28. Describe some of the ways in which lakes may be formed, and the manner in which they may disappear.

29. Contrast the coastline of the east side of the Andaman sea with that of the west side of the Bay of Bengal. Discuss the chief causes which have been operative in bringing about the more important differences.

30. Describe the broad contrasts and chief features of the land relief of the Deccan, and contrast them with those of Assam.

31. Write a short account of the various types of hills to be found in the Indian region.

32. Where are the following substances obtained *in situ* in India, and in what manner do they occur: (*a*) mica, (*b*) gold, (*c*) monazite, (*d*) iron, (*e*) manganese ore?

33. Describe the Ganges delta at the Sundarbans, and explain its general characteristics and its mode of formation and the history of the Ganges.

34. Set forth briefly but clearly the reasons for two of the following:

(*a*) It is much warmer in July than in January over India ;

(*b*) Caverns and underground streams are common in limestone districts ;

(*c*) The irregular coastline of Mergui and its Archipelago ;

(*d*) The formation of meanders and ox-bow or mortlakes.

CHAPTER XI

THE OCEAN AND ITS MOVEMENTS

27. THE PROPERTIES OF SEA WATER

1. Taste.—Taste a little sea water. Of what does it remind you? Would you describe the taste as sweet, bitter, salt, sour, or a combination of any of these?

2. Dissolved matters.—Evaporate over a water bath (Fig. 102) a measured quantity of sea water in a porcelain dish, or in a saucer over water boiling in a saucepan. Observe (*a*) the escape of bubbles of *gas* as the sea water becomes hot. Notice that these bubbles are not steam, because after the water is quite hot no more bubbles escape, although steam is given off continually until the contents of the saucer are dry.

(*b*) Note the residue of *solid matter*, which was formerly in solution. What is its appearance? If possible, weigh the dish and residue, and afterwards the dish alone, and calculate the amount of dissolved solid matter in grains per gallon or in grams per litre. Expose the residue to the air for twenty-four hours, and then re-weigh to see if it has absorbed moisture from the air. Taste the residue. To what is the taste of sea water due?

Treat river water in the same way and compare the results.

3. Density.—Weigh a bottleful of distilled water, and then the same bottle filled with sea water at the same temperature. Which is heavier?

Composition of sea water.—The character most commonly associated with sea water is its *saltness*, and this is due to the presence of salts dissolved in it. When the great solvent power of water is borne in mind, and it is remembered that there is a continual addition to the ocean by the streams and rivers which run into it in all parts of the world, all of them bringing samples of the rocks through which they have percolated, and that from the surface of the ocean a continual evaporation is going on, removing pure water and leaving the dissolved substances behind, it is not difficult to form some idea of how the saltness of the ocean is brought about. Side by side with this process, which would result in the continual increase in the amount of dissolved material, there is, however, a withdrawal of certain of the soluble ingredients by living organisms, both plant and animal, some of which extract calcium compounds, others silica, wherewith to build up their solid parts (p. 263). There is a greater tendency, therefore, for some of the dissolved compounds to increase than for others. This increase may go on in the case of the sodium chloride and calicum sulphate, until by-and-by the water can hold no more ; it becomes *saturated*, and there is a precipitation of such compounds, forming a deposit.

Moreover, from our knowledge of the occurrence of beds of salt and gypsum in the oldest fossiliferous rocks, such as the Cambrian of Iran (Persia), the Angara river in Siberia (U.S.S.R.), and perhaps those of the Punjab, and also from the nature of the plants and animals which have lived in the ocean in past ages of the world's history—information obtained from the fossil remains of such living things—there is every reason to believe that the ocean has been similarly salt since the earliest times of the life record. Among the more valuable publications of recent times dealing with the physics of the Earth is that by the National Academy of Science, Washington, volume V : " Oceanography " (*Bull.*, National Research Council, No. 85, June 1932, pp. 63-69, *et seq.*).

Though the composition of the ocean is, on the whole, wonderfully uniform, there are slight variations easily explained by local conditions ; for example, where the evaporation is much greater than the average, as in the region of the trade winds (p. 334), the percentage of dissolved material is appreciably higher. On account of evaporation also, the surface water of the ocean is sometimes salter than that below. Again, when there is a continual great addition of fresh water, as near melting icebergs, near the mouths of large rivers, or near a coast having excessive rainfall, the ocean water becomes less salt.

A typical specimen of sea water contains approximately three and a half per cent. of dissolved salts, that is to say, if 100 pounds of sea water are taken and evaporated to dryness, a residue weighing three and a half pounds is left behind.* This residue is made up of a variety of substances, present to the extent shown in the following table :

Sodium Chloride - - - - -	2·700
Magnesium Chloride - - - -	0·360
Potassium Chloride - - - -	0·070
Calcium Sulphate - - - -	0·140
Magnesium Sulphate - - - -	0·230
Calcium Carbonate - - - -	0·003
Magnesium Bromide - - - -	0·002
	3·505

Much can be learnt from a consideration of this table. First, a large part of the total solids is made up of common salt. From the fact that every hundred pounds of sea water contains between two and a half and three pounds of common salt, some conception may be formed of the enormous amount of this compound there is in the whole ocean. Though the amount of calcium sulphate is only one-seventh of a pound in one hundred pounds of sea water, yet this amount is sufficient to furnish the lime for the marine animals which possess shells and other hard parts composed of calcium carbonate (p. 263).

Gases dissolved in sea water.—Rain, from which the waters of the ocean are of course altogether derived indirectly, dissolves from the air through which it passes samples of the gases contained therein, and the continual contact of the atmosphere with water surfaces, whether those of rivers or of the ocean itself, results in a further solution of different gases. Finally, the carbon dioxide which results from the breathing of the animals of the ocean is continually being added, as well as that given off by submarine volcanoes. The result is that sea water contains from about two to three per cent. of its volume of dissolved gas. This amount is made almost entirely of oxygen, nitrogen and carbon dioxide. One half the total amount of these gases consists of nitrogen, while the other mostly consists of oxygen and carbon dioxide in about equal proportions. It is interesting to note that, while the oxygen occurs in larger proportions near the surface, the carbon dioxide is present to the greatest extent deep down.

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* The composition of sea water varies to some extent with the depth, especially where the water is very deep and undisturbed by currents. In the case of the Red Sea the evaporation is so great that the basin should fill up with salt in 200 years or so, but does not do so because there must be an outward bottom current at the straits of Bab-el-Mandeb to the Gulf of Aden. The varying composition of the water of the Dead Sea in Palestine is given by G. S. Blake in his monograph on " The Mineral Resources of Palestine and Transjordan, 1930 ".

Density of sea water.—Since sea water contains the amount of dissolved material already mentioned, it is heavier, bulk for bulk, than fresh water. If a vessel which at 4° C. exactly holds one pound of pure water is taken and filled with water from the North Pacific Ocean it is found to hold 1·0254 lb.; if water from the Red Sea is used, its weight is found to be 1·0279 lb.*; while the same volume of North Atlantic water weighs 1·0266 lb. The numbers are thus nearly the same wherever the water is obtained, and since the chemical composition is nearly constant it follows that the density varies little, one being dependent upon the other. By performing a large number of experiments on this plan and taking the mean of all the results, the number 1·0275 has been obtained, and is spoken of as the *mean density of sea water.*

Since the deeper we descend into the ocean the greater becomes the height of the water column above us, it is clear that depth and pressure increase together. Though water is only compressed slightly by a great increase of pressure, yet its molecules do become packed a little more closely together at greater depths, and the effect is seen by an increase in the density of the water. The density of the surface water has been found to be 1·0247, while water at a depth of a little more than two miles had, in one case, a density of 1·0525.

Freezing point of sea water.—Sea water freezes at a lower temperature than fresh water, but the ice formed is nearly fresh, for in freezing a large proportion of the salts is left behind. The temperature at which ice begins to form is from −2° C. to −4° C. The temperature of freezing varies a little with the amount of material dissolved in the water. Experiments show that if a solution of sodium chloride is cooled sufficiently, pure ice separates first at a temperature lower than the freezing point of pure water and that if the cooling is continued, at −22° C the whole solution freezes, forming a crystalline substance.

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* In December, 1900, the density of the water in the Suez Canal at Suez was ascertained to be 1 031, while at Ismailia it was as high as 1·038, and at Port Said as low as 1·027, but these differences are largely due to causes peculiar to this region.

Colour of sea water.—The colour of the ocean is variable from place to place, but generally in the open sea where the water is very deep it has a beautiful blue tint. When the water is shallower the colour passes from blue to shades of green. Several suggestions have been made to explain these colours, but it is quite satisfactory to regard the hue as belonging to the water itself. Pure water seen through a great thickness is quite blue in appearance. Should impurities which are not dissolved, that is, substances simply held in the water in *suspension* be present, the water may assume other tints, *e.g.* the Yellow Sea gets its name from the fact that it has been so coloured by sediment brought down by the Ho Hang Ho and other Chinese rivers; the Red Sea is said to derive its name from a microscopic plant of that colour which is at times present in large numbers on its surface; parts of the Pacific Ocean are of a red colour, due to the presence of minute animals.

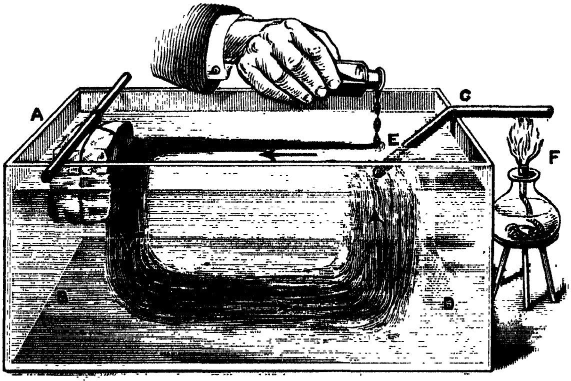

FIG. 193.—Circulation of water.

28. CURRENTS IN THE OCEANS

1. **Currents due to wind.**—Blow with bellows on the surface of muddy water in a glass tank. What depth of current can you produce without spraying up the water from the surface?

2. **Currents due to varying density.**—Place a piece of ice in a trough of water *ABCD* (Fig. 193), and at the other end of the trough arrange a metal rod *E*, kept hot by a flame *F*. Pour a little coloured water (*e.g.* red ink) into the trough, and notice the general movement of the water.

3. Study of ocean-current maps.—From a map of the world showing ocean currents (Fig. 194) answer the following questions: What is the *general* direction of the current in the equatorial part of the Atlantic, of the Pacific and Indian Oceans? Is the direction the same as that of the earth's rotation? Name any wedge-shaped land mass interposed in the path of the equatorial current of the *Atlantic*. In what manner is the direction of the current thereby modified? What becomes of each branch? Does either branch divide again? Can you suggest a cause for the division? Do the currents of the Atlantic show any resemblance to whirlpools or *eddies*? Describe any Atlantic eddies as *clockwise* if the direction is like that of the hands of a watch lying face up, or *anti-clockwise* if the opposite. What currents in the Atlantic flow from polar seas towards the equator?

Into what branches does the westward equatorial current of the *Pacific* divide? Suggest a cause for the division. Does either branch divide? Why? How many eddies are to be seen in the Pacific? Describe the course of any currents flowing into the Pacific from polar oceans.

What is the general direction of flow in the Antarctic Ocean? Do the currents form an eddy? What is the projection (Chapter III) of your map? If the Antarctic currents were shown on a polar projection, would they appear as an eddy? If so, would the direction of flow be clockwise or not, coincide with the earth's rotation or not? If possible examine the course of the Antarctic currents on a globe.

Ocean currents.—Several causes are at work tending to produce movements in the waters of the oceans, but it is most probable that the **prevailing winds** constitute the chief motive force resulting in the production of the great *regular* movements of the water referred to under the term **ocean currents.** In this connection the comparative shallowness of the ocean (p. 163) must be again insisted upon, for it is only by bearing this in mind that any conception of the power of the wind can be attained.

The principal ocean currents.—North and south of the equator, blowing with unceasing regularity, occur the systems of air currents known as the **trade winds** (Chapter XIV). In the northern hemisphere these winds blow between latitudes 6° N. and 35° N. from the north-east to the south-west; while in the southern hemisphere they blow throughout corresponding latitudes from the south-east

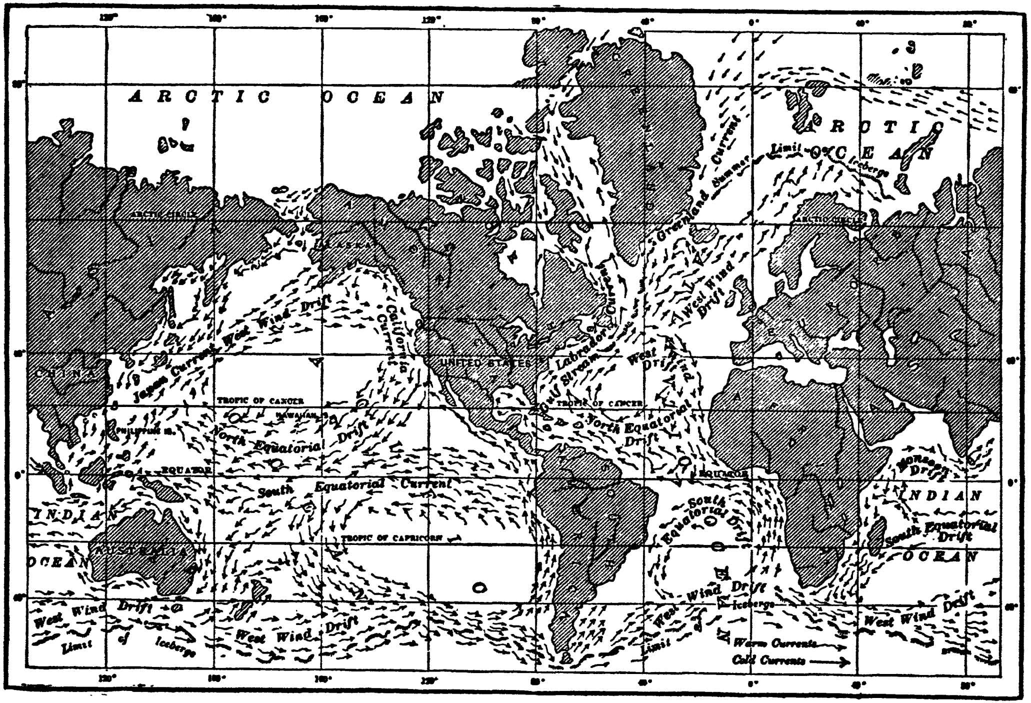

FIG. 194—Map of Ocean Currents. (Adapted from Tarr's " Physical Geography ", Macmillan.)

towards the north-west. The consequence is that they meet in the neighbourhood of the equator, and the resultant wind, acting upon the waters, causes the latter to move towards the west. Were there no land masses to interfere with its course, a great equatorial current round the earth would be produced. But the continents of South America and Africa extend in a northerly and southerly direction, that is, at right angles to the path of the current, and prevent its continuous course round the globe, causing it by coming into contact with the land to divide into the various currents which will be described immediately.

Secondary causes assisting in the formation of ocean currents are:

The *rotation of the earth,* which causes a body of water moving polewards to have a tendency in an easterly direction and one moving towards the equator a tendency towards the west.

Any change in the *extent of the polar ice caps* modifies local currents. Such modifications are most pronounced in the southern hemisphere, where several currents are indirectly affected.

Evaporation and *precipitation* of water must also be mentioned. Their effect on the great ocean currents is small. With the water brought in by rivers, they are the chief cause of the currents noticed in inland seas and in the straits that connect them with the ocean.

Temperature inequalities and *differences in atmospheric pressure* also exert some influence in the formation of ocean currents, but, compared with the effect of the winds, their work in this directon is almost negligible.

In inland seas, however, differences of atmospheric pressure are sometimes of importance, giving rise to disturbances of the water known as *seiches.*

The following account of the principal ocean currents is based upon a summary by Mr. W. J. Humphreys, published in the " Meteorological Chart of the North Pacific Ocean ", of the U.S. Weather Bureau.

North Atlantic.—The *North Equatorial Current* is driven by the trade winds across the Atlantic. This **warm current** has a velocity of about 15 to 25 miles a day. Reaching the coast of South America, part passes north. The greater portion of this reaches the Caribbean Sea and eventually becomes the *Florida Current,* the name given to the eastern current flowing along the north coast of Cuba. Being diverted to the north-east, the Florida Current becomes the important **Gulf Stream,** one of the swiftest and most important of the ocean currents. Off the coast of New England the Gulf Stream turns due east, the direction of the prevailing winds, and flows on until about half-way across the Atlantic. Here, at about long. 40° W., lat. 42° N., this great warm current fans out into a broad slow current that covers the ocean from Spain to Iceland and extends round Norway to Spitsbergen and Nova Zembla. This extended continuation of the Gulf Stream is known as the *Gulf Stream Drift.* The wind which determines the direction of the Gulf Stream Drift is warm and moisture-laden, and this air tempers the climates of the British Isles and other countries, the windward sides of which are bathed by the drift. The temperature of the water itself differs but very slightly from that of the land.

Besides the warm currents enumerated, the North Atlantic includes three important **cold currents**: The *East Greenland Current* flows from the Arctic Ocean in a south-westerly direction along the east coast of Greenland, and eventually turns north-west into Davis Strait. The *Labrador Current,* a continuation of the East Greenland Current, flows south off the coasts of Labrador and Newfoundland, and disappears as a surface current at the northern edge of the Gulf Stream. The *Canary Current* (or *West Wind Drift*), which is cold for its latitude, flows south and south-west between the Sargasso Sea (p. 340) and the west coast of Africa.

South Atlantic.—A slow moving current of cold water crosses the Atlantic between lats. 40° and 60° S. from west to east in the direction of the prevailing winds under the name of the *West Wind Drift.* Much of the West Wind Drift turns north off the west coast of South Africa and continues as the *Benguela Current,* which is cold for its latitude. The Benguela Current, under the influence of the trade winds, turns westward and crosses the ocean as the *South Equatorial Current.* Approaching South America, it divides near Cape St. Roque into a northern and southern portion ; the first merges into the North Equatorial Current, and the second flows along the south-east coast of Brazil as a warm current known as the *Brazil Current.*

North Pacific.—Corresponding to the currents in the North Atlantic Ocean, we have here a *North Equatorial Drift* flowing under the influence of the trade winds as a broad **warm** current, with a velocity of 12 to 20 miles a day, all the way from the American coast to the Philippine Islands. Just north of the equator an irregular current of varying width is found flowing east, counter to, and between, the north and south equatorial currents ; it is the *Counter Equatorial Current.* It is about 300 miles wide near America, and tapers to a wedge near the Philippines. The greater part of the North

Equatorial Current passes north under the name of the *Kuroshiwo*, or *Japan Current*. The Japan Current is narrow and swift and corresponds to the Gulf Stream. It eventually spreads out, and following the direction of the prevailing winds, flows east to North America, where, with the northern part of the North Equatorial current, it becomes the somewhat cold *California Current*. A cold current also flows south-west from the Bering Sea along Kamchatka to Japan.

South Pacific.—As in the South Atlantic, a cold Antarctic (West Wind) Drift Current flows eastward across the Pacific between lats. 40° and 60° S. A large part of it turns north off the coast of South America, and becomes known as the *Peru Current*. The Peru Current near Cape Blanco takes a westerly direction, and, following the direction of the trade winds from South America, crosses the Pacific Ocean to about long. 180° as the *South Equatorial Current*. Part of the last-named current, passing among the Pacific Islands, turns south along the south-east coast of Australia as the *East Australian Current*, which eventually merges with the Antarctic Drift.

Indian Ocean.—The Antarctic Drift Current is in evidence in the Indian Ocean also ; part of it turns north near the south-west corner of Western Australia, becoming the *West Australian Current*. The trade winds give rise to a *South Equatorial Drift* flowing west from Australia to the north of Madagascar ; part of this takes a southerly direction off the east coast of Madagascar, and merges with the Antarctic Drift. During northern winters nearly all, and during southern winters still a portion, of the South Equatorial Current reaching the north of Madagascar turns south near the African coast, which it follows as a warm current, first under the name *Mozambique* and then *Agulhas*, round the southern extremity of Africa. A south-west **Monsoon Current** flows only during the northern summer, when most of the South Equatorial Current turns, near Madagascar, and flows north-west along the African coast under the influence of the south-east monsoons, and then east by way of Ceylon to Sumatra. During the northern winter the monsoons are from the north-cast (Chapter XIV), and during this time there is a surface current from Sumatra westward to the coast of Africa.

Full particulars of the currents and other details of importance in navigating the Indian Ocean and adjoining seas opening towards India will be found in the following publications of the Hydrographic Department of the Admiralty, and are available at His Majesty's Stationery Office, London : " South Indian Ocean Pilot ",

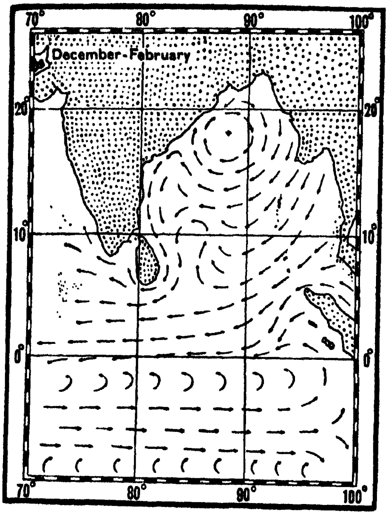

FIG. 195.

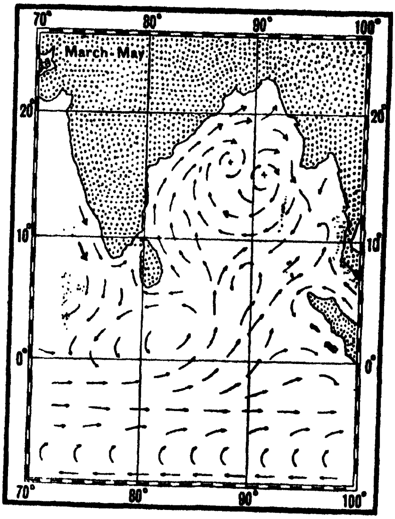

FIG. 196.

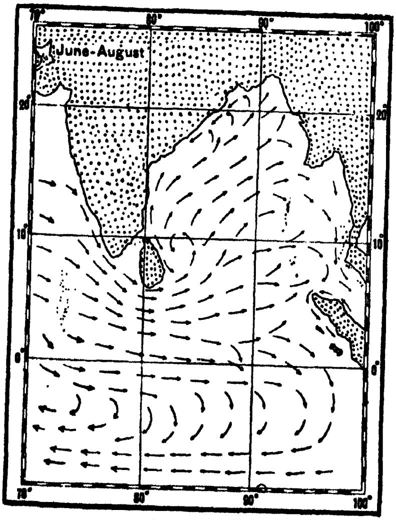

FIG. 197.

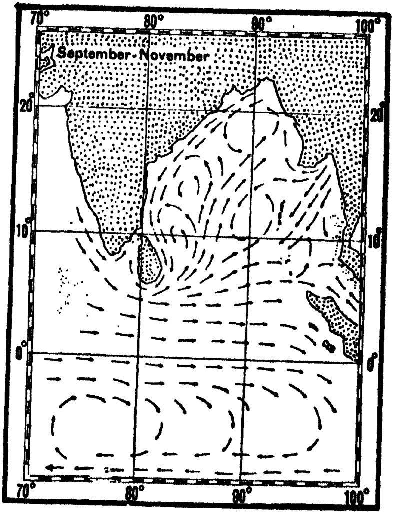

FIG. 198.

Surface currents in the Bay of Bengal throughout the year.

5th Edn., 1934; "Bay of Bengal Pilot", 6th Edn., 1931; "West Coast of India Pilot", 7th Edn., 1926; "Persian Gulf Pilot", 8th Edn., 1932; and "Red Sea and Gulf of Aden Pilot", 8th Edn., 1932. Among old books of considerable interest there is the "Bay of Bengal Pilot", 1879, by J. F. Imray.

The ocean currents considered as systems of vortices.—An examination of a map showing the ocean currents reveals the fact that the currents can be arranged into groups, each forming a huge vortex with comparatively still water in its centre. Thus, if the course of the following currents in the North Atlantic, *viz.* the Equatorial, Guiana, Gulf Stream and Guinea is traced, it will be seen that they form a complete cycle, the currents constituting the circle all moving in the direction of the hands of a watch or "clockwise", and forming a right-handed vortex. Conversely, the Equatorial and the Brazil currents with the northward-moving cold water from the Antarctic which passes up past Cape Colony along the west coast of Africa, together make up a left-handed vortex, or one moving in the opposite direction to the hands of a watch, *i.e.* "anti-clockwise".

In the Pacific Ocean, too, the Equatorial and the Japan currents, with the continuation of the latter down the west coast of North America, can all be considered as making up a right-handed vortex or a system of currents moving in a clockwise manner in the North Pacific; whereas the Equatorial and New South Wales currents with the colder Antarctic drifts all move in an anti-clockwise manner, forming a left-handed vortex in the South Pacific.

The central part of each of these vortices is comparatively still water, and its existence is marked by a luxuriant growth of seaweeds, including one, the *Sargassum bacciferum,* from the presence of which the still area of the North Atlantic is called the **Sargasso Sea.** Within this region there is also an abundant animal life. Probably these seaweed-covered districts have supplied many of the oft-reported sea-serpents, for to an imaginative mariner at a distance the gentle up and down movements of water thus covered could be construed easily into the serpentine movement of some huge sea-monster.

Temperature.—The general effect of heat upon liquids is to make them expand, causing a given mass to occupy a larger volume and so become lighter, bulk for bulk. The heating effect of the sun in tropical regions, therefore, causes a rising of the lighter waters, and a sinking of the heavier colder waters of "higher" latitudes to take their place.

The general result of a difference of temperature in equatorial and polar regions is that there is a tendency for a warm surface current to flow into higher latitudes. This becomes sufficiently cooled, by its arrival at lat. 60°, to sink. Also a cold current of fairly fresh water, formed by the melting of icebergs, creeps along the surface from the poles towards the equator, but sinks about lat. 60°. This circulation or convection action can be illustrated experimentally (Fig. 193).

29. THE TIDES

1. Interval between successive times of high water. (*a*) *Outdoor work.*—At any seaside place or at any point on a tidal river which possesses a tide gauge or other convenient scale of feet, observe as nearly as possible the time of high water day after day. How does your estimate agree with the expected time of high water as announced for the day? What is the interval between high water from day to day? Is it always the same?

(*b*) Consult tide-tables of the Indian Ocean or *Whitaker's Almanack* or some other convenient source of information and find out the intervals between successive times of high water at any place for a month. Are they always the same? What is the average of the intervals?

2. Interval between successive southings of the moon.—Find the intervals between successive southings of the moon (given in Whitaker's and other almanacs) for a month. Are they always the same? What is the average interval? How does it compare with the average interval between successive times of high water?

3. Spring and neap tides.—(See tables on pp. 348 and 349). On what dates was the range between high and low water (*a*) greatest, (*b*) least, at Bhavnagar on the west coast of India during September 1936? How do these dates agree with the phases of the moon in the same month (p. 344)? Is a similar agreement to be seen between the moon and tides during June 1937? In each month the tides with a greater range than usual between high and low water are called *spring tides*; those with a smaller range than usual are called *neap tides*. What sort of tides is evidently to be expected at new moon, first quarter, full moon and last quarter respectively?

Have spring tides the greater range in June or in September?

4. Establishment of ports.*—*The time of high water at any port on the day of new or full moon is called the establishment of the port.*

(*a*) Look up in the tide-tables of the Indian Ocean for 1936 the time of high water at Dublat (Sagar Island) which occurs next after the hour of new moon in each month. Take the average of these 13 times of high water to find the establishment of the mouth of the Hooghly river at Sagar Island. Similarly, from *Whitaker's Almanack,* find the establishment of London Bridge from the times of high water next following full moon. How do the results compare?

(*b*) From the tide-tables find out if there is any constant, or nearly constant, interval between the times of high water at Dublat (Sagar Island), Diamond Harbour and Kidderpore (Calcutta) day by day for a month. What is the establishment of Kidderpore (Calcutta)? Obtain it directly as in (*a*) and compare the results.

(*c*) Find out similarly the establishments at Karachi, Bombay, Colombo, Madras, Chittagong, Rangoon and Mergui. Mark the seven establishments on a map.

(*d*) *To find the approximate time of high water at any place on any date.*†—To the time of the moon's southing on that date add the establishment of the port. Using the establishments given on p. 351, find in this manner the time of high water at Mascat, Mormugao, Moulmein and Mergui on the day of new moon at Easter of the year of your copy of the tide-tables of the Indian Ocean.

5. Study of tide chart. (*a*) *Cotidal lines.*—Examine Fig. 205. How long does it take a tide wave to travel from the west coast of Ireland to (i) Liverpool, (ii) Hull, (iii) the mouth of the Thames?

Trace the progress of the tidal wave from Galway to the Mull of Galloway.

At what places off the coast of Great Britain shown on Fig. 205, and at what approximate times on the day of full moon, do two tide waves meet?

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* The "*establishment of the port*" is the average interval which elapses between the moon's transit across the meridian (*i.e.* moon's southing), at full moon and at change of (new) moon, and the occurrence of high water. Since at these times the moon crosses the meridian at twelve o'clock, either of day or night, the "establishment" is the hour of high water at full and change.

† A very rough determination of the time of high water is to add the solar time of high water on the days of full and change of moon to the time of the moon's passage over the meridian.

Compare the times of high water at Dover and Liverpool.

(*b*) *The set of tidal streams.*—Examine Figs. 199 and 200. At what places are the directions of neighbouring streams sharply contrasted? Make notes of the directions and speeds of the tidal streams at the following regions, (i) when the water is falling at Dover and Liverpool, (ii) when the water is rising at Dover and Liverpool: Off the mouth of the English Channel, off the south coast of Ireland, in St. George's Channel, in the Bristol Channel, in the Gulf of St. Malo,* east and west of the Straits of Dover, off Valentia Island, along the west coast of Ireland, in the North Channel, between the inner and outer Hebrides, along the north coast of Scotland. How do the tidal streams differ in direction at any (the same) time along the east coast of Great Britain?

Where, round the British Isles, do you suppose such charts are likely to be of the greatest value to seamen? Why?

(*c*) From a *Whitaker's Almanack* find the time of high water at London Bridge which occurs next after the hour of full and change of moon each month, and thus ascertain the establishment of London Bridge (the Port of London).

Phases of the Moon, June 1937

	D.	H.	M.
Last Quarter - - -	2	5	23·5
New Moon - - -	8	20	43
First Quarter - - -	15	19	28
Full Moon - - -	23	22	59·5
In Perigee - - -	8	30	222,580 miles
In Apogee - - -	20	20	252,140 ,,

Phases of the Moon, September 1937

	D.	H.	M.
New Moon - - -	4	22	58·5
First Quarter - - -	12	20	57·1
Full Moon - - -	20	11	32·4
Last Quarter - - -	27	5	43·3
In Perigee - - -	12	17	227,830 miles
In Apogee - - -	27	3	251,180 ,,

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* A return of the vessels wrecked on the Channel Islands shows that the greater part of them ran ashore about the end of the falling water at Dover.

Phases of the Moon, June 1936

Full Moon - - -	5	5	20
Last Quarter - - -	12	12	5
New Moon - - -	19	5	15
First Quarter - - -	26	19	23
In Perigee - - -	15	21	
In Apogee - - -	27	20·5	

Phases of the Moon, September 1936

	D.	H.	M.
Full Moon - - -	1	12	37
Last Quarter - - -	8	3	14
New Moon - - -	15	17	41
First Quarter - - -	23	22	12
Full Moon - - -	30	21	1
In Perigee - - -	3	8·8	
In Apogee - - -	19	00·7	

N.B.—The times given in the foregoing tables, and in those on pp. 348-9 and 351, are for Standard or Greenwich Mean time (0^h is midnight; 12^h is noon); if Indian Standard time be required, *add* 5 hours 30 minutes. If Calcutta local time is required, *add* 23 minutes 20 seconds to Indian Standard time, as the meridian of Calcutta is 88° 20′ E. long.

General observations.—Everyone must have noticed when at the seaside or along the banks of a tidal river that during every day there are what are known as two "high waters" and two "low waters".* The former are called "high tides", and the latter, "low tides". Moreover, when the height of the water is increasing, or when low tide is giving place to high tide, it is a *flood tide*; whereas, when the high tide has been reached and the height of the water is becoming lower—as the low tide is approached—we have the *ebb tide.*

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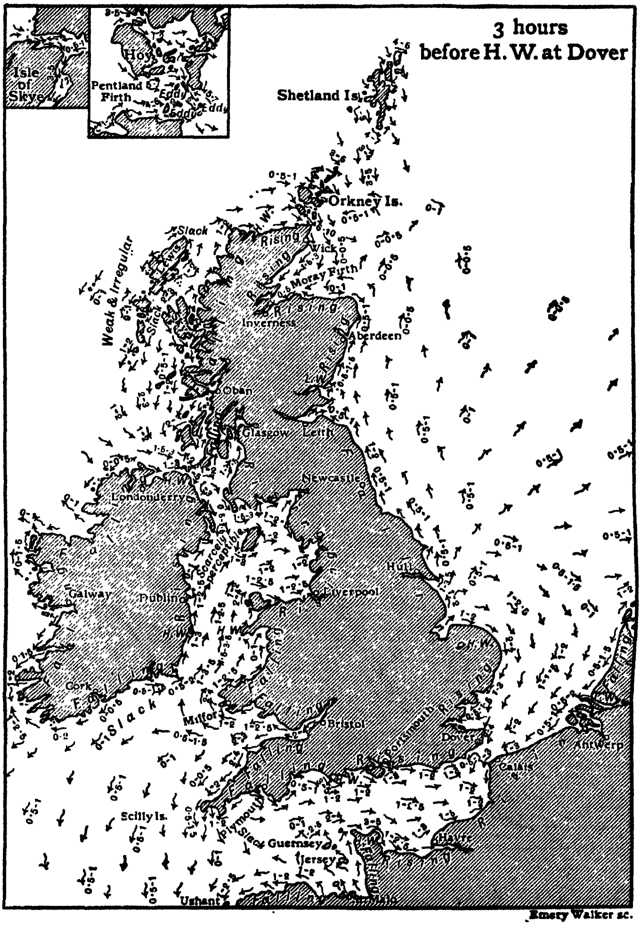
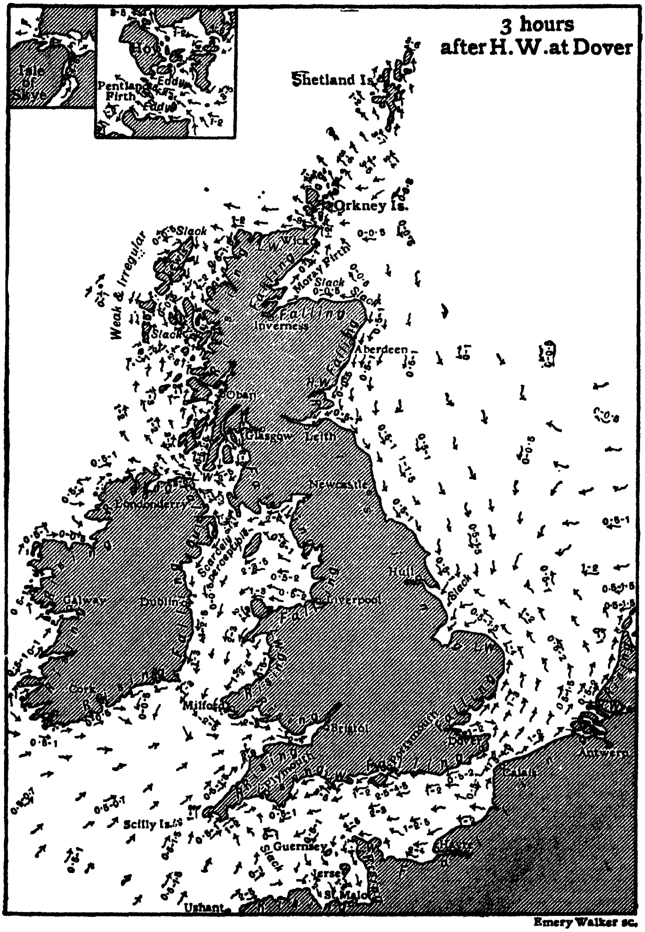
* "The *Tide* is a rising and falling of the water of the sea produced by the attraction of the sun and moon. A rise and fall of the sea produced by a regular alternation of day and night breezes, by regular rainfall and evaporation, or by any influence of the weather cannot strictly be called a tide, although they may be distinguished as meteorological tides. True astronomical tides in the atmosphere may be shown by a regular rise and fall of the barometer, but such tidal effects are very small. It is erroneous to speak of the large wave caused by an earthquake as a tidal wave." C. M. Thompson, Survey of India, Monograph on "The Tides".



Emery Walker sc.

FIG. 199.—Chart of tidal streams 3 hours before high water at Dover. (Speeds are given in knots, that is, nautical miles per hour.)

" The terms *ebb* and *flow* in tidal rivers are not synonymous with *rise* and *fall,* for at the moment of high water the current is most rapid upstream and at low water most rapid downstream. Hence the tidal current 'flows' long after high water has passed and 'ebbs' for a long time after low water and when the water level is rising. As a consequence the tide in rivers rises quicker than



Emery Walker sc.

FIG. 200.—Chart of tidal streams 3 hours after high water at Dover. (Speeds are given in knots, that is, nautical miles per hour.)

it falls, and a shorter time elapses between low and high water than between high and low water." C. M. Thompson, Survey of India, Monograph on "The Tides".

This phenomenon is well shown in the following tide-table for the Hooghly river during the period January 24 to 26, 1936, after the new moon of January 24, 1936.

TIMES OF HIGH AND LOW WATER AND HEIGHTS IN FEET

	High water Jan. 24		Low water		High water		Low water Jan. 25		High water	
	H. M.	FT.	H. M.	FT.	H. M.	FT.	H. M.	FT.	H. M.	FT.
Dublat (Sagar I.)	10 23	14·4	16 49	2·3	23 43	16·1	5 20	1·7	11 1	15·3
Diamond Harbour	12 4	14·3	20 6	1·9	0 23	16·5	8 34	0·4	12 37	15·4
Kidderpore, Calcutta	14 10	13·7	22 47	3·6	2 29	15·5	11 15	2·3	14 43	14·7

	Low water		High water		Low water Jan. 26		High water		Low water	
	H. M.	FT.	H. M.	FT.	H. M.	FT.	H. M.	FT.	H. M.	FT.
Dublat (Sagar I.)	17 28	1·7	23 21	16·6	5 56	1·0	11 41	15·8	18 9	1·4
Diamond Harbour	20 46	1·4	0 56	17·2	9 11	0·3	13 15	16·1	21 25	1·3
Kidderpore, Calcutta	23 28	3·4	3 1	16·3	11 51	2·3	15 17	15·5	0 7	3·4

DIFFERENCES IN TIME BETWEEN HIGH AND LOW WATER AND ALSO BETWEEN LOW AND HIGH WATER

	Between high and low water			Between low and high water		
	H. M.		H. M.	H. M.		H. M.
At Dublat - - -	6 26	to	6 37	5 54	to	5 41
Diamond Harbour -	8 2	to	8 15	4 17	to	4 3
Kidderpore - - -	8 37	to	8 50	3 42	to	3 26

N.B.—It will also be noticed that when it is Low Water at Kidderpore it is High Water at Dublat (Sagar Island).

TIDE TABLES FOR JUNE, 1936

HOOGHLY RIVER, INDIA

Day	DUBLAT Lat. 21° 38′ N. Long. 88° 08′ E.				Week Day	DIAMOND HARBOUR Lat. 22° 11′ N. Long. 88° 11′ E				Week Day	KIDDERPORE Lat. 22° 32′ N. Long 88° 20′ E			
	HIGH		LOW			HIGH		LOW			HIGH		LOW	
	Time	Ht	Time	Ht.		Time	Ht	Time	Ht		Time	Ht	Time	Ht.
	h m	ft.	h m	ft.		h m	ft.	h m	ft		h m	ft.	h m	ft.
1 M	07 22	14·1	01 05	5·8	M	09 00	14·0	03 48	4·5	M	11 27	14·0	06 43	5·1
	19 36	13·4	13 44	6·3		21 15	13·4	16 28	4·7		23 39	13·3	19 24	5·5
2 Tu	08 08	14·8	01 57	5·5	Tu	09 44	14·6	04 45	4·2	Tu	—	—	07 40	5·2
	20 17	13·9	14 32	5·8		21 55	13·8	17 23	4·2		12 04	14·7	20 17	5·2
3 W	08 45	15·4	02 40	5·0	W	10 22	15·4	05 36	3·9	W	00 11	13·8	08 29	5·2
	20 54	14·3	15 13	5·4		22 30	14·3	18 10	3·8		12 36	15·4	21 02	5·0
4 Th	09 19	15·9	03 18	4·7	Th	10 55	16·0	06 20	3·6	Th	00 43	14·3	09 11	5·1
	21 25	14·7	15 49	5·2		23 04	14·7	18 51	3·5		13 07	15·9	21 41	4·9
5 F	09 49	16·2	03 51	4·5	F	11 27	16·4	06 59	3·3	F	01 14	14·7	09 49	5·2
	21 56	14·8	16 24	5·0		23 35	14·9	19 29	3·3		13 38	16·3	22 18	4·8
6 S	10 21	16·4	04 25	4·2	S	11 59	16·7	07 35	3·1	S	01 43	15·0	10 23	5·1
	22 29	14·8	16 58	4·7		—	—	20 04	3·1		14 06	16·7	22 52	4·7
7 𝔖	10 54	16·4	04 59	4·2	𝔖	00 10	15·0	08 09	3·0	𝔖	02 15	15·2	10 58	5·2
	23 06	14·8	17 31	4·6		12 35	16·8	20 37	2·9		14 40	16·8	23 25	4·8
8 M	11 31	16·4	05 33	4·2	M	00 48	15·0	08 43	3·0	M	02 52	15·2	11 33	5·2
	23 46	14·8	18 06	4·4		13 14	16·8	21 13	2·9		15 18	16·7	23 58	4·8
9 Tu	—	—	06 10	4·2	Tu	01 28	15·0	09 19	3·1	Tu	03 33	15·2	—	—
	12 11	16·3	18 45	4·4		13 56	16·6	21 49	2·9		16 02	16·4	12 08	5·2
10 W	00 30	14·8	06 51	4·5	W	02 14	14·8	09 57	3·3	W	04 23	15·1	00 33	4·9
	12 54	16·0	19 28	4·5		14 41	16·3	22 26	3·0		16 53	16·0	12 45	5·3
11 Th	01 19	14·7	07 37	4·9	Th	03 04	14·7	10 35	3·5	Th	05 21	14·6	01 09	5·0
	13 40	15·7	20 16	4·7		15 30	15·9	23 03	3·2		17 52	15·3	13 22	5·4
12 F	02 11	14·5	08 32	5·5	F	03 58	14·7	11 20	3·8	F	06 24	14·4	01 46	5·1
	14 35	15·2	21 13	5·2		16 26	15·4	23 52	3·4		18 55	14·7	14 07	5·6
13 S	03 22	14·3	09 42	5·9	S	05 05	14·8	—	—	S	07 32	14·3	02 36	5·3
	15 47	14·8	22 21	5·2		17 35	14·9	12 21	4·3		20 03	14·4	15 11	5·8
14 𝔖	04 42	14·7	11 01	6·0	𝔖	06 23	14·9	00 53	3·7	𝔖	08 47	14·5	03 43	5·3
	17 06	14·6	23 34	5·0		18 50	14·7	13 36	4·5		21 19	14·3	16 29	5·9
15 M	05 58	15·2	—	—	M	07 37	15·2	02 06	3·7	M	10 03	14·8	04 59	5·3
	18 21	14·7	12 23	5·8		20 02	14·7	14 59	4·2		22 31	14·4	17 52	5·7
16 Tu	07 07	15·8	00 46	4·7	Tu	08 45	15·8	03 26	3·4	Tu	11 12	15·2	06 18	5·1
	19 29	15·0	13 37	5·4		21 06	15·0	16 22	3·7		23 32	14·6	19 11	5·3
17 W	08 08	16·6	01 53	4·3	W	09 44	16·6	04 46	3·1	W	—	—	07 36	5·1
	20 26	15·4	14 39	4·8		22 01	15·5	17 34	3·2		12 02	15·8	20 22	5·0
18 Th	08 58	17·2	02 51	4·0	Th	10 33	17·4	05 52	3·0	Th	00 18	15·0	08 39	5·1
	21 14	15·8	15 34	4·4		22 49	16·1	18 33	2·8		12 48	16·5	21 19	4·8
19 F	09 40	17·5	03 42	3·9	F	11 15	18·0	06 46	2·9	F	01 02	15·6	09 33	5·2
	21 56	15·9	16 19	4·2		23 32	16·5	19 22	2·5		13 31	17·3	22 09	4·7
20 S	10 20	17·5	04 26	3·6	S	11 57	18·1	07 35	2·8	S	01 43	16·0	10 23	5·3
	22 37	15·8	17 01	3·9		—	—	20 05	2·2		14 09	17·6	22 55	4·7
21 𝔖	11 01	17·4	05 07	3·7	𝔖	00 15	16·5	08 18	2·8	𝔖	02 24	16·0	11 04	5·5
	23 18	15·8	17 39	4·0		12 39	18·0	20 44	2·3		14 50	17·4	23 32	4·8
22 M	11 40	17·1	05 45	3·8	M	00 58	16·4	08 54	2·8	M	03 04	15·9	11 42	5·7
	23 59	15·6	18 15	4·1		13 21	17·7	21 19	2·6		15 31	17·2	—	—
23 Tu	—	—	06 21	4·2	Tu	01 40	16·1	09 30	3·1	Tu	03 47	15·7	00 07	5·1
	12 19	16·6	18 48	4·4		14 02	17·1	21 52	2·9		16 13	16·8	12 16	5·8
24 W	00 40	15·2	06 56	4·8	W	02 20	15·6	10 01	3·5	W	04 32	15·3	00 38	5·3
	12 57	16·0	19 23	4·8		14 41	16·4	22 21	3·4		16 58	16·0	12 46	6·0
25 Th	01 19	14·8	07 34	5·5	Th	03 02	15·1	10 32	4·0	Th	05 20	14·8	01 05	5·5
	13 34	15·3	20 01	5·5		15 21	15·5	22 50	3·9		17 44	15·2	13 15	6·1
26 F	02 02	14·2	08 16	6·2	F	03 46	14·4	11 05	4·6	F	06 09	14·2	01 36	5·7
	14 17	14·4	20 46	6·1		16 05	14·7	23 25	4·4		18 32	14·3	13 53	6·2
27 S	02 54	13·8	09 09	7·0	S	04 37	13·9	11 45	5·2	S	07 01	13·8	02 10	5·9
	15 12	13·7	21 40	6·6		16 56	13·9	—	—		19 21	13·5	14 36	6·6
28 𝔖	03 59	13·6	10 16	7·7	𝔖	05 38	13·7	00 12	4·8	𝔖	08 02	13·6	02 59	6·1
	16 20	13·1	22 46	6·9		18 02	13·2	12 47	5·8		20 25	13·0	15 39	6·8
29 M	05 14	13·4	11 35	7·7	M	06 51	13·5	01 16	5·1	M	09 16	13·6	04 05	6·3
	17 36	12·8		—		19 16	12·7	14 02	6·0		21 43	12·8	16 57	6·8
30 Tu	06 30	13·8	00 02	6·8	Tu	08 05	13·4	02 32	5·2	Tu	10 34	13·8	05 22	6·3
	18 49	12·8	12 55	7·6		20 27	12·9	15 25	5·8		22 56	12·8	18 18	6·7

TIDE TABLES FOR SEPTEMBER, 1936

HOOGHLY RIVER, INDIA

Day	DUBLAT Lat. 21° 38′ N Long 88° 08′ E.				Week Day	DIAMOND HARBOUR Lat. 22° 11′ N. Long. 88° 11′ E.				Week Day	KIDDERPORE Lat. 22° 32′ N. Long. 88° 20′ E.			
	HIGH		LOW			HIGH		LOW			HIGH		LOW	
	Time	Ht.	Time	Ht.		Time	Ht	Time	Ht.		Time	Ht	Time	Ht.
	h m	ft	h m	ft		h m	ft	h m	ft		h m	ft.	h m	ft.
1 Tu	09 28	18·0	03 43	2·9	Tu	11 08	19·6	06 49	1·8	Tu	00 55	20·0	09 47	7·2
	21 44	18·1	16 05	2·2		23 19	19·6	19 11	1·0		13 14	21·0	22 10	6·7
2 W	10 01	18·8	04 20	2·0	W	11 37	20·5	07 31	1·1	W	01 27	21·1	10 31	7·0
	22 20	18·9	16 39	1·5		23 54	20·6	19 50	0·6		13 46	21·8	22 50	6·6
3 Th	10 37	19·1	04 56	1·7	Th	—	—	08 11	0·7	Th	02 01	21·9	11 11	6·8
	22 57	19·1	17 14	1·3		12 11	20·8	20 27	0·4		14 21	22·1	23 29	6·8
4 F	11 14	18·8	05 33	1·9	F	00 29	20·9	08 48	0·8	F	02 37	22·2	11 50	6·8
	23 37	18·8	17 49	1·7		12 47	20·5	20 59	0·7		14 58	21·9	—	—
5 S	11 53	18·1	06 11	2·6	S	01 09	20·6	09 20	1·3	S	03 17	21·9	00 03	6·8
	—	—	18 25	2·5		13 28	19·5	21 29	1·4		15 38	21·1	12 24	7·0
6 Ꞩ	00 19	18·0	06 49	3·7	Ꞩ	01 52	19·5	09 50	2·3	Ꞩ	03 57	20·9	00 32	7·0
	12 32	16·9	19 01	3·7		14 10	18·0	21 55	2·5		16 16	19·7	12 52	7·2
7 M	01 01	16·8	07 28	5·0	M	02 37	17·9	10 17	3·5	M	04 39	19·7	00 56	7·3
	13 14	15·3	19 40	5·1		14 56	16·0	22 20	3·6		16 59	18·0	13 17	7·6
8 Tu	01 51	15·3	08 20	6·4	Tu	03 27	16·2	10 50	4·7	Tu	05 28	17·9	01 20	7·7
	14 16	13·7	20 40	6·5		15 52	14·0	22 59	4·8		17 52	16·2	13 49	8·3
9 W	03 12	13·9	09 46	7·5	W	04 39	14·3	—	—	W	06 36	16·6	01 53	8·5
	15 56	12·5	22 20	7·5		17 28	12·7	12 04	5·7		19 22	14·9	14 52	9·0
10 Th	04 59	13·1	11 39	7·6	Th	06 31	13·3	00 44	5·7	Th	08 36	15·4	03 30	9·0
	17 49	12·5	—	—		19 22	12·8	13 57	5·7		21 29	14·9	16 52	8·9
11 F	06 37	13·7	00 19	7·3	F	08 14	14·0	02 45	5·6	F	10 31	16·1	05 44	9·1
	19 15	13·6	13 15	6·8		20 51	14·1	15 41	4·8		23 04	16·3	18 46	8·3
12 S	07 46	14·9	01 41	6·2	S	09 24	15·4	04 20	4·8	S	11 37	17·6	07 24	8·7
	20 09	14·9	14 15	5·5		21 49	15·6	16 57	3·6		23 57	17·7	20 01	7·6
13 Ꞩ	08 28	15·9	02 32	5·3	Ꞩ	10 10	16·5	05 26	3·7	Ꞩ	—	—	08 24	8·2
	20 45	16·1	14 55	4·6		22 25	16·9	17 51	2·7		12 16	18·7	20 50	7·4
14 M	09 00	16·8	03 11	4·3	M	10 37	17·6	06 13	2·9	M	00 29	18·9	09 09	7·9
	21 14	16 8	15 29	3·8		22 50	17·9	18 32	2·2		12 45	19·7	21 29	7·4
15 Tu	09 28	17·2	03 45	3·7	Tu	11 02	18·4	06 52	2·4	Tu	00 56	19·9	09 48	7·7
	21 42	17·3	16 00	3·3		23 14	18·7	19 06	1·9		13 11	20·3	22 05	7·4
16 W	09 52	17·5	04 14	3·4	W	11 25	18·7	07 23	2·0	W	01 21	20·5	10 20	7·6
	22 08	17·6	16 26	3·2		23 38	19·0	19 34	1·9		13 35	20·6	22 33	7·5
17 Th	10 19	17·4	04 41	3·3	Th	11 50	18·6	07 52	2·0	Th	01 47	20·7	10 50	7·5
	22 35	17·6	16 51	3·2		—	—	20 01	2·1		14 00	20·5	23 00	7·5
18 F	10 46	17·1	05 08	3·5	F	00 05	18·9	08 18	2·1	F	02 14	20·7	11 17	7·4
	23 03	17·3	17 16	3·5		12 17	18·2	20 25	2·3		14 27	20·2	23 25	7·5
19 S	11 12	16·5	05 34	4·1	S	00 33	18·6	08 43	2·4	S	02 42	20·4	11 44	7·5
	23 30	16·9	17 40	4·0		12 45	17·6	20 46	2·7		14 53	19·6	23 48	7·5
20 Ꞩ	11 40	15·8	05 58	4·7	Ꞩ	01 02	18·0	09 04	2·9	Ꞩ	03 11	19·9	—	—
	—	—	18 04	4·6		13 15	16·6	21 05	3·1		15 21	18·7	12 06	7·6
21 M	00 00	16·1	06 24	5·6	M	01 34	17·0	09 21	3·6	M	03 39	18·9	00 06	7·5
	12 08	14·9	18 30	5·4		13 46	15·5	21 23	3·7		15 49	17·5	12 26	7·7
22 Tu	00 31	15·2	06 54	6·4	Tu	02 08	16·0	09 44	4·5	Tu	04 10	17·8	00 22	7·6
	12 40	13·9	19 01	6·3		14 21	14·3	21 42	4·6		16 23	16·3	12 45	7·9
23 W	01 10	14·2	07 33	7·3	W	02 49	14·9	10 09	5·4	W	04 49	16·6	00 41	7·9
	13 25	12·7	19 46	7·1		15 07	12·8	22 14	5·4		17 06	15·0	13 10	8·3
24 Th	02 07	13·3	08 35	8·1	Th	03 44	13·5	10 56	6·2	Th	05 41	15·6	01 08	8·4
	14 35	11·8	21 02	7·7		16 11	11·4	23 23	5·9		18 09	13·9	13 51	8·9
25 F	03 37	12·6	10 13	8·3	F	05 10	12·6	—	—	F	07 07	14·8	02 05	8·7
	16 24	11·5	22 51	7·6		17 57	11·3	12 31	6·2		19 58	13·5	15 12	9·0
25 S	05 21	12·9	—	—	S	06 58	13·0	01 12	5·9	S	09 06	14·8	04 05	8·7
	18 04	12·6	12 03	7·4		19 45	12·7	14 20	5·6		22 01	14·5	17 20	8·4
27 Ꞩ	06 45	14·1	00 32	6·8	Ꞩ	08 28	14·3	03 03	5·0	Ꞩ	10 43	16·0	06 08	8·4
	19 18	14·3	13 20	5·9		21 01	14·7	15 51	4·1		23 12	16·6	18 55	7·8
28 M	07 42	15·7	01 43	5·3	M	09 25	16·0	04 27	3·7	M	11 37	17·7	07 31	7·8
	20 05	16·2	14 11	4·3		21 45	16·8	17 00	2·6		23 53	18·3	19 58	7·1
29 Tu	08 21	17·1	02 31	3·8	Tu	10 01	17·8	05 27	2·3	Tu			08 26	7·2
	20 39	17 8	14 50	2·9		22 15	18·6	17 47	1·5		12 10	19·2	20 45	6·7
30 W	08 54	18·1	03 12	2·7	W	10 29	19·2	06 15	1·2	W	00 24	19·9	09 13	6·7
	21 12	18·7	15 28	1·8		22 46	20·0	18 34	0·6		12 40	20·4	21 31	6·4

" The terms *rise*, *range* and *height* of the tide may be defined as follows : The ' rise ' of the tide is the difference in level between high water and the datum of the chart. The ' range ' of the tide is the difference in level between any high water and the following low water, or between any low water and the following high water. The ' height ' of the tide is the difference at any moment between the level of the water and the datum of the chart." (" Tide-Tables of the Indian Ocean for the year 1936 ", p. xxii, 1935.)

The sloping part of the shore included between the high and low water marks is known as the *foreshore*.

But if the observer is not content with these general observations, and takes notice of the times at which high tide occurs on several successive days, he will be struck with the fact that the time of high tide on any one day is nearly an hour later than on the immediately preceding day. Actual observations, say for a period of a month, will show a variation from about 24 minutes to an hour and fifteen minutes, but the average disparity is about forty-eight minutes. Thus, if it is high water anywhere, say, at Kidderpore or Karachi, at 6 o'clock to-night, it will be high water at approximately 6·48 p.m. tomorrow. At some places the rise and fall of the water are recorded by means of a tide guage.

The moon, too, gets about 48 minutes later every day, *i.e.* she crosses the meridian, or souths, about 48 minutes later every day. The interval between two successive passages of the moon across the meridian is what is called a lunar day, and in this period there are always two high tides.

These constant coincidences suggest a connection between the moon and the tides. There is one of an intimate kind, the nature of which will be now explained.

Connection between the moon and the tides.—Coastguardsmen and others have observed repeatedly that when the shadow of a flagstaff or similar object thrown by moonlight has a certain direction, it is high tide ; or, what is the same thing, when it is high tide, the shadow of a fixed object thrown by moonlight always has a peculiar direction. At Colombo high water occurs about two hours after the moon has crossed the meridian ; so that if the moon is shining and has southed, high water is not far off, but at Madras it

(HARMONIC) TIDE-TABLE FOR SOME PORTS OF THE INDIAN OCEAN AT PERIOD OF CHANGE OF MOON

Port	Lat.	Long.	Time per port	On January 24, 1936 at 12 h. 21 m. G.M.T.						On July 18, 1936 at 11 h. 57 m. G.M.T.					
				High water			Low water			High water			Low water		
				H.	M.	FT.	H.	M.	FT.	H.	M.	FT.	H.	M.	FT.
Zanzibar -	6° 9′ S.	39° 11′ E.	37° 30′ E.	15	15	11·6	21	56	1·3	15	30	12·8	21	50	1·2
Aden -	12° 47′ N.	44° 59′ E.	45° E.	20	50	7·1	2	20	3·7	19	0	6·3	2	4	0·1
Suez - -	29° 56′ N.	32° 33′ E.	30° E.	23	42	6·1	5	53	1·7	23	41	5·7	5	58	0·6
Mascat -	23° 37′ N.	58° 36′ E.	L.M.T.	22	23	8·6	4	13	3·2	20	59	7·2	3	38	0·6
Karachi -	24° 48′ N.	66° 58′ E.	I.S.T. (82° 30′)	23	54	9·7	*5	56	2·81	22	42	8·4	†5	12	0·3
Bombay -	18° 55′ N.	72° 50′ E.	I.S.T.	*0	39	15·9	*6	53	3·5	†0	1	12·6	†5	58	1·6
Colombo -	6° 57′ N.	79° 51′ E.	I.S.T.	14	50	2·1	20	29	0·5	14	18	1·9	20	48	0·0
Minicoy -	8° 17′ N.	73° 3′ E.	I.S.T.	11	16	4·2	17	55	1·5	12	34	4·8	18	51	2·9
Madras -	13° 6′ N.	80° 18′ E.	I.S.T.	20	51	3·8	*3	8	0·1	20	28	2·7	†2	35	0·3
False Pt. -	20° 25′ N.	86° 47′ E.	I.S.T.	21	28	8·5	*3	38	1·0	21	3	7·9	†3	8	2·5
Sagar I. -	21° 38′ N.	88° 8′ E.	L.M.T.	22	43	16·1	*5	20	1·7	22	0	16·0	†4	29	3·4
Diamond H.	22° 11′ N.	88° 11′ E.	L.M.T.	*0	23	16·5	*8	34	0·4	23	29	17·0	†7	34	2·8
Kidderpore	22° 32′ N.	88° 20′ E.	L.M.T.	*2	29	15·5	*11	15	2·3	†1	34	17·3	†10	15	6·4
Chittagong	22° 20′ N.	91° 50′ E.	I.S.T.	13	23	9·9	20	29	0·8	12	41	15·4	20	2	2·1
Elephant Pt.	16° 30′ N.	96° 18′ E.	97° 30′	16	17	18·9	23	11	3·2	15	33	21·2	22	38	3·7
Rangoon -	16° 46′ N.	96° 10′ E.	97° 30′	16	48	16·9	*0	20	2·0	16	10	19·2	23	52	2·7
Mergui -	12° 26′ N.	98° 36′ E.	97° 30′	23	05	17·8	*5	39	1·4	22	48	15·4	†4	58	2·1
Port Blair -	11° 41′ N.	92° 46′ E.	97° 30′	22	18	7·1	*4	49	0·0	22	12	5·8	†4	0	1·3
Penang -	5° 25′ N.	100° 21′ E.	110° E.	13	6	6·9	19	20	1·7	15	15	7·1	22	0	2·1
Singapore	1° 16′ N.	103° 50′ E.	110° E.	23	46	8·8	*4	58	4·5	22	20	9·8	*5	20	0·6

* January 25, 1936. † July 19, 1936. L.M.T. = Local Mean Time.

is nearly 8 hours later and at Karachi more than 10 hours to high tide after the new moon has crossed the meridian. We are not always able to see the moon even at night on account of clouds, but the times at which the moon crosses the meridian of London are calculated and tabulated (see tide-tables for the Indian Ocean).

Great discrepancies occur in tidal predictions for riverain ports, such as Calcutta, Rangoon and Moulmein, owing to river freshets, shallow foreshores, and the configuration of the estuaries, and special computations are necessary in such cases. It has been found that in the examples given below the interval *after* the moon's transit, or southing, is as follows :

		High water	Low water
1.	Dublat (Sagar Island)	35 hours	29 hours
	Diamond Harbour	36 ,,	32 ,,
	Kidderpore	39 ,,	35 ,,
2.	Chittagong	38 ,,	33 ,,
3.	Elephant Pt.	40 ,,	35 ,,
4.	Rangoon	41 ,,	36 ,,
	Amherst	39 ,,	34 ,,
	Moulmein	40 ,,	37 ,,

1. Hooghly river; 2. Karnafuli river; 3. Rangoon river; and 4. Moulmein river.

It is plain that there is a connection between the time of high water and the time of the moon's passage across the meridian. The interval between the time at which the moon crosses the meridian of a place and high water at that place is roughly constant, but it differs in amount for different places. The interval between the time of high water and the immediately preceding meridian passage is known as the **establishment of a port**, or, *since the moon souths about midday on the day of the new moon, the establishment of a port may also be defined as the time of high water at any place on the day of new moon.*

The average interval elapsing between the full or new (change of) moon and the spring tide is called " the Age of the Tide ", as it represents the age or interval which the tide is assumed to take to reach a place after the moon's southing, or meridian passage at full change of moon. The age of the tide influences the " establishment of a port " and for this reason the " mean establishment of a port " is generally used, as its value is not dependent on the age of the tide. It is computed as follows : Select a month's tidal registration and the date and time of the new moon, convert astronomical to civil time for the value of the transit as below :

Date	Time of high water in local mean time	Time of moon's transit at Greenwich in G.M.T.	Luni-tidal interval

The time of high water is always *after* that of the moon's transit, hence the former will be greater. Take the mean of all the luni-tidal intervals with reference to the time of the moon's transit at Greenwich. The moon's departure 48 minutes in 24 hours (*i.e.* 2 minutes an hour) for longitude East of Greenwich is made. The resulting value is the Mean Establishment of the Port.

Tides in the ocean and in inland seas. Range of tides.—The difference in the height of the water at high and low tides in the open sea is not more than about two or three feet. A few observations only have been made, but these were obtained at oceanic islands. Tides in the Mediterranean sea are so small—only about three or four inches—that usually they cannot be recognised, being obliterated by the effects of wind and other disturbing causes. Similarly, tides in the great North American lakes, in the Caspian and other inland seas, are nearly imperceptible. In shallow water, or in a converging gulf, this difference in height, or, as it is commonly called, the **range of the tides**, is increased (see p. 350).

Tidal rivers.—If the channel of a tidal river is of uniform width from its mouth landwards, that is, if its width contracts but slowly, the range of the tide decreases on account of friction. Thus, in the Moulmein river, in January, the range of the tide at Amherst is between 19 feet and barely 5 feet, and at Moulmein the range of the tide in the same month is between only 10 feet and 5 feet. In September, during the rains, when the river is in flood, the range of the tide at Amherst is between 22 feet and 5 feet, while at Moulmein, in the same month, the range of the tide is between 12 feet and only 3 feet. In the Thames (Fig. 200), the mean range at Sheerness is about 20 feet, at London Bridge about 15, and at Kew Bridge 7 feet. On the other hand, where a river contracts rapidly, the tidal range increases from the mouth towards its source. Thus, at the entrance of the Bristol Channel the total rise at the highest tides is about 18 feet, at Swansea about 30, and at Chepstow about 50 feet. This high wave is known as a **bore** (p. 195).

During the dry months, *e.g.* March to May, the range of the tide in the Hooghly varies between 11 feet to 4 feet at Sagar, 15 feet to 7 feet at Diamond Harbour, and 15 feet to 7 feet at Kidderpore; but in the rains, in September, when the river is in flood, the range of the tide in the Hooghly is between 18 feet to only 4 feet at Sagar, 20 feet to 7 feet at Diamond Harbour, and 16 feet to 4 feet at Kidderpore, although the tide rises higher at all these places during the rains. The Hooghly is often subject to bores and so also is the Megna, the Pegu river, the Sittang, and the Gulf of Cambay (Fig. 124).

How the moon causes tides.—Newton's law of gravitation states that *every body in nature attracts every other body with a force which is directly proportional to the product of their masses, and inversely proportional to the square of the distance between their centres of gravity; and the direction of the force is in the line joining the centres of gravity of the bodies.* The **force of gravity** acting between the moon and the earth thus tends to draw them together. The earth and moon, however, are revolving round their common centre of gravity (which is 3000 miles from the earth's centre), and a **centrifugal force** is thereby set up which exactly counterbalances the force of attraction and keeps the two bodies apart. This centrifugal force is the same at every part of the earth; but the force of the moon's attraction differs at different places on the earth. At the earth's centre the moon's attraction is equal to the centrifugal force.

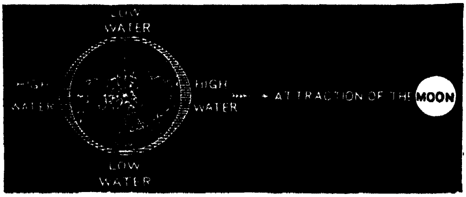


FIG. 201.—The tide-raising action of the moon.

Suppose the earth at rest and completely covered by an ocean (Fig. 201). Since the waters on the right side of the earth in the diagram are nearer to the moon than is the centre of the earth it is apparent that the attraction of the moon on these waters will be greater than upon the centre of the earth, and therefore greater than the centrifugal force. Since the particles of water move over one another easily, the waters in question are pulled up into a heap.

Similarly, the centre of the earth is nearer to the moon than are the waters on the left of the diagram, and the pulling force on these waters is therefore less than the centrifugal force. The waters thus, in the circumstances, tend to be piled up not only under the moon but also on the opposite side of the earth, and to be depressed as a necessary result at right angles to this, that is, at the places marked " low-water " in Fig. 201. Such is a general explanation of what is known as the equilibrium theory of the tides.

Referring again to Fig. 201, the student must understand that it is not the attraction of the moon for the earth and the waters covering it as a whole which causes the tidal wave. The tide-generating cause is found in the *difference* between the attraction upon the various waters and that upon the centre of the earth ; in other words, in the difference between the moon's attraction upon the waters and the action of centrifugal force on them.

Were the earth without any diurnal rotation, as well as completely covered with water, the lunar tides would, if there were no friction between the water and the surface of the solid earth, be dragged continually round the earth. The effective force in tide-making is of course the horizontal component only of the total tide-generating force, and this varies, both in magnitude and direction, from place to place on the earth, and according to the moon's position in the sky. High tides thus occur at different intervals after the moon's meridian passage, and hence we get the establishment of ports.

Differential nature of the attraction exerted by the moon and sun.—If the student has understood the way in which the moon causes the tidal wave, he will have thought that, as the relative positions of the sun and earth are at various seasons analogous with those of the moon and the earth, the sun, too, ought to produce tides. This is the case. Were there no moon, the effect of the sun's attraction would be felt in the formation of a tide wave, which, however, would not be nearly so pronounced as the one caused by the moon. The *differential attraction* in the case of the moon is more marked than in the case of the sun, and the tide-producing effect of the moon is about two and a half times as great as that of the sun. This follows from the law of gravitation (p. 354). For although the sun's mass is so much greater than the moon's, its distance from the earth is also very much greater than the moon's ; and therefore the difference of its attraction upon the earth's surface and at the centre is less than in the case of the moon.

Spring and neap tides.—There are thus four sets of tides :

Lunar Tide.	Solar Tide.
Anti-lunar Tide.	Anti-solar Tide.

The expression anti-tide is used to signify the tide on the side of the earth away from the sun and moon. When the solar tides coincide with the lunar tides, so that the effects are superimposed, we have *Spring Tides* (Fig. 202). When the crests of the two tidal waves are as far apart as possible we get **Neap Tides** (Fig. 203).

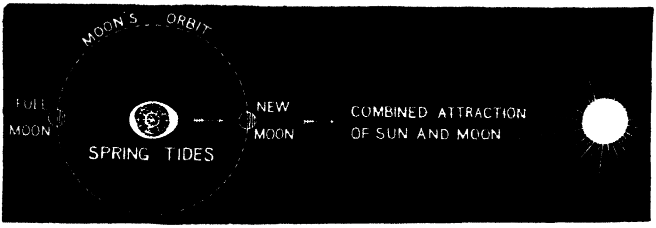


FIG. 202.—Condition for spring tides.

The height of high water and the fall of low water are not always the same. Shortly after new and full moon high water is higher and low water lower than usual. These constitute what we have referred to as **Spring Tides.** On the days following the first and last quarters, the difference between the heights of high and low water is little more than half as much as at Spring Tides. These tides, where the range is unusually small, are the **Neap Tides** ("nipped" or restricted tides). These monthly variations are due to the combination of the attractions of the moon and sun upon the waters of the ocean. At the time of Spring Tides, the tide-raising forces of the moon and sun act together, while at Neap Tides they are opposed. (See tide-tables for the Indian Ocean.)

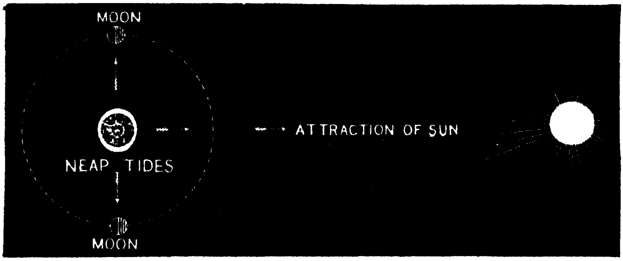


FIG. 203.—Condition for neap tides.

Other variations.—The range of heights of the tides varies with the positions of the sun and moon with reference to the earth's equator, as well as with the distances of these bodies from the earth. The range is greatest when the sun and moon are nearest the earth and nearest to the plane of the earth's equator. These " highest " tides occur when the moon is in perigee (nearest the earth) and near the equator, that is, at the equinoxes, in March and September. The least range occurs at the solstices, in June and December, when the sun is farthest away from the equator, and the moon is at its greatest distance from the earth, that is, in apogee, at the same time. The former are the *equinoctial tides*, and the latter the *solstitial tides.*

The diurnal inequalities in the tides, owing to the varying declination of the sun and moon, can be represented by supposing a diurnal tide high only once in a lunar day of 24 hours 50 minutes, combined with a semi-diurnal tide high twice in this period, also a diurnal tide high once in a solar day of 24 hours combined with a semi-diurnal tide high twice in this period.

The moon's declination goes through a complete cycle of changes in a lunar month—half north and half south of the equator—at corresponding periods. The chief tidal components in most localities are :

1. Lunar and solar semi-diurnal tides ;
2. Lunar and solar diurnal tides ;
3. Lunar fortnightly and solar semi-annual tides ;
4. Lunar monthly and solar annual tides.

The moon's distance from the earth is different in different parts of its orbit, which is an ellipse with the earth at one of its foci, but the orbit modifies. The lunar orbit is inclined to the earth's orbit at 5° 8′ 40″. The points where the two orbits intersect are the **Nodes.** The point of the lunar orbit nearest the earth is the **Perigee,** and the most distant the **Apogee,** and the line joining them the line of **Apsides.** Both the line of the Nodes and of the Apsides change their position, the former rotates once in 18·6 years and the other in nearly 9 years, due to the sun's disturbing influence (after C. M. Thompson, Survey of India, monograph on " The Tides ").

Co-tidal lines.—The tidal wave does not travel across the ocean with its theoretical velocity. The varying depths of the water, the friction with the bottom, and other disturbing causes, make this impossible. But though its velocity alters from place to place, the time of high tide will be exactly the same at many stations. If we join on a map all such places where high tide occurs at the same time, we shall cover the map with **co-tidal lines**,* which are *lines showing contemporary tides.* The map of the co-tidal lines of the world (Fig. 204) shows the form which these lines take. Suppose a parent wave to start at 12 o'clock noon in the middle of the South Indian Ocean. It reaches Madagascar and the Maldive Archipelago about eight hours later, combines with a wave in the Atlantic Ocean, and arrives off the British Isles at noon on the following day. It also combines with the lunar tide raised in the Pacific twelve hours later and this wave reaches New Zealand 12 hours after, or, a day after it started in the South Indian Ocean.

The nature of tide waves.—When we speak of the motion of a tidal wave, it must not be imagined that the mass of water of which the wave is composed has this motion. The particles of water surface only *vibrate* at right angles to the direction in which the wave is travelling. A ship, for instance, floating upon the open sea is not carried forward by the progressive waves, but simply rises and falls as they advance and retire. The actual movement of the water particles is, however, rotary, *i.e.* in circular or harmonic motion, in the open sea. Thus, while a particle Q moves round in a vertical circle, a point P will move up and down by simple harmonic motion which can be resolved in a simple sine curve. This is the same method usually adopted for tidal wave computations.

Tidal streams.—The oscillating *vertical* movement of the waters, of which tide-**waves** consist, must be distinguished clearly from that regular flow of **horizontal** movement of the surface waters, constituting tidal **streams**, to which in shallow waters the tides give rise. Such tidal streams tend to sweep along with them ships and other floating objects, and are therefore a source of danger in navigation near the shore and in tidal rivers such as the Hooghly. For example, the true stream in the northern part of the Bay of Bengal will always carry a vessel towards the Sandheads, while the water is rising at False Point on the Orissa coast, and from it while it is falling at that place. Examination of Figs. 199 and 200 shows that the directions of tidal streams depend on local circumstances entirely, since at the same moment neighbouring streams may be running in diverse directions. Their directions change, however, with perfect regularity, as the passage of the tidal wave causes low water to be succeeded by high, and high water in its turn by low. It is therefore

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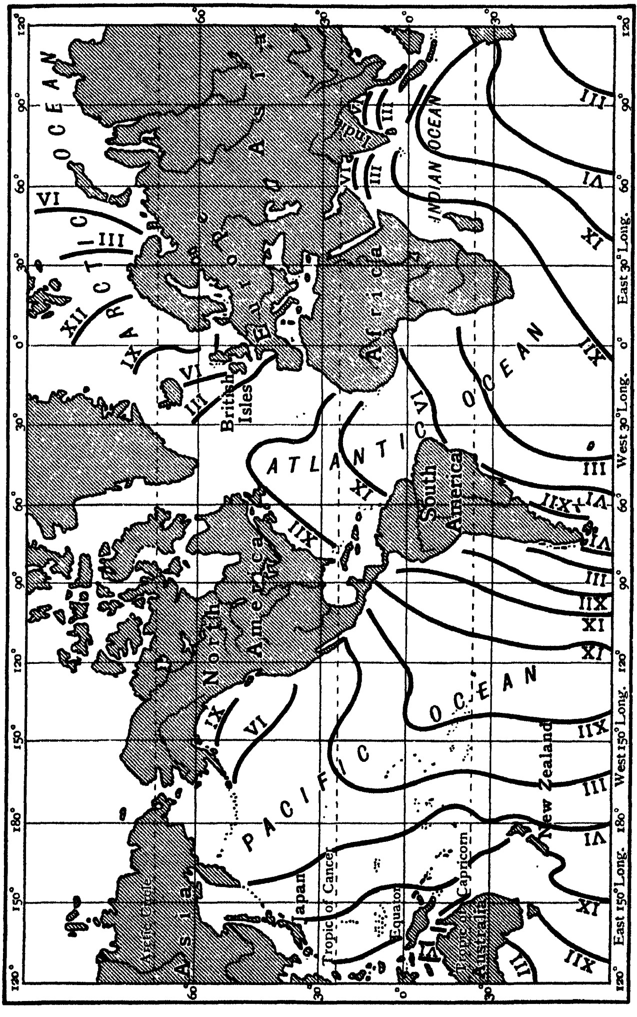
* Co-tidal Maps. To depict the progress of the tide across a body of water, use is made of so-called " Co-Tidal Lines ". A co-tidal line is a line connecting the points in a body of water at which high water occurs simultaneously. And since the tidal day has the same length as the lunar day, co-tidal maps make use of co-tidal hours, which are lunar hours referred to the meridian of Greenwich. (The co-tidal hour is the time of high water in lunar time referred to the meridian of Greenwich.)

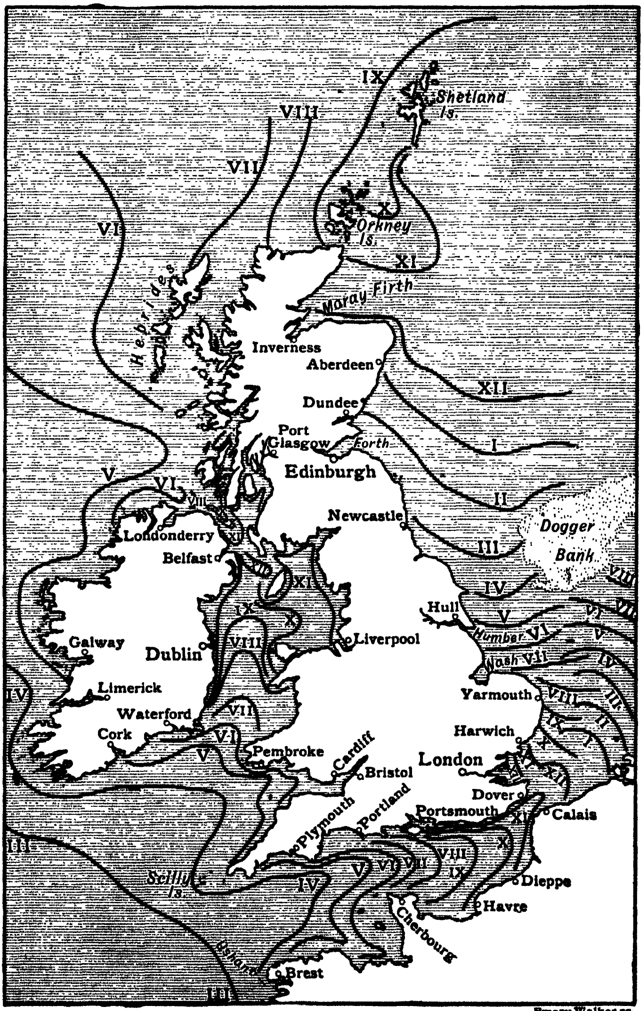


Emery Walker sc.

FIG. 204.—Co-tidal lines of the world.

possible to predict with certainty the "set" or direction of the tidal stream at any place for each hour of the tide. Armed with the

Admiralty charts of tidal streams—from which Figs. 199 and 200 are copied—the mariner in home waters, knowing his position and able to refer to tables for the state of the tide at Dover or at False



Emery Walker sc.

Fig. 205.—Co-tidal lines of the British Isles.

Point or at any other place, turns at once to the particular chart which shows the currents affecting his vessel at the time. More detailed information respecting the direction and rate of the streams is given in the official tide tables issued each year by the Admiralty.

EXERCISES ON CHAPTER XI

1. Spring tides at Karachi rise to a height of about 10 feet, at Bhavnagar to 36 feet, at Bombay to 16 feet, and at Minicoy to 5 feet. When high tide occurs at noon at Karachi, there is high tide at Bombay at 12.22 p.m., at Bhavnagar at 5.30 p.m., and at Minicoy at 12.26 p.m. Explain why the times and the heights of the tides at these places are so different.

2. How are the tides produced? What is the difference between spring tides and neap tides, and how is this difference caused?

3. Describe the principal ocean currents of the North Indian Ocean and their effects on the climate of western India and eastern South Africa.

4. Describe the extent and course of the ocean current commonly known as the Monsoon Drift. State why it is so named, whether the reason is in accordance with fact, and how it is at variance with fact during the North-East Monsoon in the Bay of Bengal.

5. Describe briefly the passage of the tidal wave up the Arabian Sea and Bay of Bengal, and explain the conditions which prevail (*a*) in the Gulf of Cambay, (*b*) in the Hooghly to Calcutta, (*c*) in the Moulmein river.

6. Write a brief account of the importance of the tides in the Hooghly, and describe the character of the tides of the Hooghly at the James and Mary sands during the South-West Monsoon.

7. How are the tides caused? Describe the tidal phenomena off the east coast of England and in the Irish Sea.

8. Explain generally how tides are formed, and why some are higher than others. Draw an outline map of the North Indian Ocean, including the Arabian Sea and the Bay of Bengal, and insert the co-tidal lines.

9. On January 1, 1936, high water occurred at the following places at the times stated: Zanzibar, 8.7 a.m. (time of 37° 30′ E.); Aden, 0.27 a.m. (time of 45° E.); Karachi, 3.26 a.m. (time of 82° 30′ E., *i.e.* I.S.T.); Port Okha, 5.2 a.m. (I.S.T.); Porbandar, 3.7 a.m. (I.S.T.); Port Albert Victor (Kathiawar), 7.20 a.m. (I.S.T.); Bhavnagar, 9.30 a.m. (I.S.T.); and Bombay, 4.15 a.m. (I.S.T.). Explain why, in places so near one another as Bombay and Bhavnagar, there should be such great differences in the time of high water.

10. What is meant by (*a*) spring tides, (*b*) neap tides? Under what circumstances do neap tides occur?

11. Explain the course of the tidal wave around the coast of India. Explain any peculiarities in the tides of the Gulf of Cambay, the estuary of the Hooghly, and in the Andaman Sea.

12. It is customary nowadays to say that the Gulf Stream does *not* reach the British Isles. Explain, as accurately as you can, what is meant by " the Gulf Stream ". Give the reasons for its existence and for its comparatively high temperature. Indicate its climatic effects (direct and indirect) and its influence on navigation. Illustrate your answer by a sketch map.

13. On first coming to Britain the Roman soldiers were astonished at the tides. A Latin author, Tacitus, says of Great Britain, " the tide does not flow and ebb merely as far as the shore, but streams and winds deep inland among ridges and mountains, as though it were its own realm." How do you explain this paragraph? Why should the tides of Great Britain fill the people of Rome with surprise?

14. What is meant by high tide, low tide, and foreshore? Why do the height of the tide and the extent of the foreshore vary at different places?

15. What changes would be observed in the hour and the height of high tide, if the observations were continued at a place for one month? State briefly the cause of each difference that would be noticed.

16. What is meant by spring tides and neap tides, and when do they occur?

17. Account for the fact that the range of tides in the Gulf of Cambay is very great compared with that in the Pamban Pass between India and Ceylon and in the Hooghly estuary below Diamond Harbour.

18. What modifications must be introduced to make the following statements quite accurate?

(*a*) " If the sun is not shining at midday, the north can easily be determined by the direction of the needle of a mariner's compass."

(*b*) " A straight line is drawn on the map to show the shortest passage a ship can take from New York to Bristol."

(*c*) " After high tide the salt water immediately begins to run out from the coastline, and after low tide to run towards the land."

19. Indicate and account for the position of warm and cold currents in the North Indian Ocean.

What is meant by the " Continental Shelf "? Describe its outline from Burma to Java.

On what parts of the Bay of Bengal are the most valuable fisheries?

20. Trace the course of the tide round the British Isles.

Why do some places have four tides a day?

21. To what causes are ocean tides due? Describe the conditions most favourable for the production of high tides.

22. Describe briefly the systems of ocean currents of the oceans south of the equator, and state the effect of these currents upon the temperature of the coastal lands bordering the South Indian and Atlantic Oceans.

PART III

CLIMATE

CHAPTER XII

TEMPERATURE IN RELATION TO CLIMATE

30. THE COMPARISON OF TEMPERATURES

1. Heat and temperature.—Heat a quart of water in a suitable vessel until the water feels neither warmer nor cooler than your hand, and notice *how long* it takes to heat the water to this extent. Now heat half a pint of similar water in the same vessel with the same burner or lamp burning at the same rate and at the same distance from the vessel, and notice how long the water must be heated to make it as warm as your hand. Has the quart or the half pint received more heat from the burner? Which is hotter?

Which is hotter, a teaspoonful of boiling water or a gallon of lukewarm water? Which contains more heat? Does the hotness or coolness of a body depend entirely on the amount of heat it contains?

The state of hotness or coolness of a body is called its *temperature*.

2. Mercury as a temperature indicator.—(*a*) Examine an ordinary laboratory thermometer. What is the liquid inside it? Put it in water and heat the water to boiling. At what point on the scale is the top of the mercury column then? Notice whether its position alters as the boiling is continued. Do you think that boiling water gets any hotter as the boiling is continued? Give reasons for your answer.

Put the thermometer in oil, or melted tallow, and heat the vessel containing it. Does the mercury in the thermometer rise higher when immersed in the oil than it did in boiling water. Do you think boiling oil has a higher or a lower temperature than boiling water? Give reasons for your answer.

Put the bulb of the thermometer in water in a beaker and surround the beaker by a mixture of salt and pounded ice. Stir the water with the thermometer and notice and describe the alteration in the level of the mercury column. What is its position on the scale when the water begins to freeze? Does the freezing water get any colder as the freezing continues?

Take the thermometer out of the beaker and plunge it into the surrounding mixture of ice and salt. What is the scale reading now?

Is the instrument you have used a Centigrade (marked " C " or " Cent.") or a Fahrenheit (marked " F " or " Fahr.") thermometer?

3. Comparison of thermometer scales.—(*a*) Compare a Centigrade and a Fahrenheit thermometer. On the former the boiling point of water is marked 100° and the freezing point of water 0° ; while on the latter these two temperatures are marked 212° and 32° respectively.

4. Maximum and minimum thermometers.—Examine maximum and minimum thermometers. Experiment with them by alternately warming (by contact with the hand) and cooling (by blowing) the bulb. Notice in each case how the index is affected, how the instrument is " set ", and whether it is used in a horizontal or a vertical position. Make a drawing showing the nature and position of the index. What limits of temperature are respectively indicated by the thermometers? Are the scales Fahrenheit or Centigrade?

Heat and temperature.—Temperature may be described in very general terms as the degree of hotness of a body. We may take two different quantities of water and expose them for equal times to the same source of heat. It is common experience that the smaller amount of water is made warmer thereby than the larger quantity. An amount of heat which would raise the temperature of a teaspoonful of water to the boiling point would scarcely make a quart of water appreciably warmer. The temperature of the boiling water is said to be higher then than that of the cooler water, though the *amount* *of heat* it contains may be very much smaller. If a body at a high temperature and one at a low temperature are brought into contact, there is a passage of heat from the former to the latter until they are both at the same temperature. Hence, we can also define temperature as a condition of bodies that determines which of two bodies when placed in contact will part with heat to the other.

Evidently temperature is analogous to the level of water, for if two cisterns containing water at different levels be put in connection, there will be a flow of water from that in which the water stands at the higher level to the other until the water in both cisterns assumes the same level.

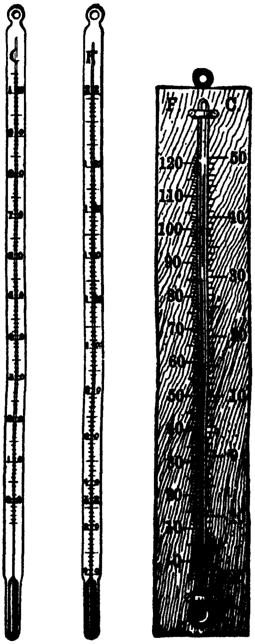


FIG. 206.—Common form of thermometer.

The indication of temperature. The thermometer.—The change of size which bodies experience when heated can be made to provide a method of indicating the change of temperature which bodies undergo. If some form of matter which expands regularly as it is heated can be found, the increase in volume which results can be taken as an indication of the change of temperature. Thus, if mercury in a tube rises through a certain distance for a certain change of temperature, this rise of the level of the mercury in the tube can be looked upon as an equivalent of a certain change of temperature; and it may be argued that if, as the result of its contact with any other body, the mercury rises again to this extent, then the body with which it is in contact has caused it to experience an equivalent change of temperature, and that the body is at the temperature represented by the higher level of the mercury. An arrangement of this kind is called a **thermometer.**

Two kinds of thermometer scales are in common use (Fig. 206).

One is known as the **Centigrade** scale, and the other as the **Fahrenheit** scale. When a thermometer is placed in melting ice, the mercury in it remains at the same level so long as any ice is unmelted. This level of the mercury marks what is called the **Freezing Point**, because at this temperature water freezes. The freezing point is marked 0° (read "no degrees") on a Centigrade thermometer, and 32° on a Fahrenheit thermometer. A thermometer placed in the steam from water boiling at sea level records the same temperature so long as the water continues to boil. The level at which the mercury stands is called the **Boiling Point**, because at this temperature water begins to boil. The boiling point is marked 100° on the Centigrade thermometer and 212° on the Fahrenheit thermometer. It is thus seen that a degree on the Centigrade thermometer represents a greater difference of temperature than a degree on the Fahrenheit thermometer. Hence, in speaking of the temperature of the air at a place, for example, we must be careful always to state with what kind of thermometer the temperature was measured. Degrees on a Centigrade thermometer are always written with C. after them, thus, 0° C. and 100° C.; while degrees on the Fahrenheit thermometer are followed by F., thus, 32° F. and 212° F.

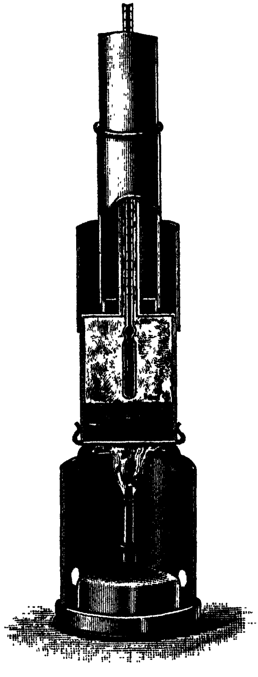


FIG. 207.—Hypsometric apparatus.

The hypsometer.—As will be explained in a later chapter, the pressure of the atmosphere becomes less with an increase of altitude. Now the temperature at which water boils depends upon the pressure of the atmosphere; the greater the pressure of the air above the boiling water, the higher the temperature of boiling. When we say that the temperature of boiling water is 100° C. or 212° F., it is understood that the water is boiling at sea level. Water boils at temperatures lower than

100° C. at places above sea level, the higher the altitude the lower being the temperature of boiling. These facts are made use of by explorers to determine the heights of mountains above sea level. Having determined the temperature at which water boils at the place of observation, it is possible by calculation, after reference to tables, to find out the height of the place above sea level. Such tables are included in " Hints to Travellers ", published by the Royal Geographical Society (8th edition, vol. i, pp. 209 to 214). An examination of Fig. 207 will show how the apparatus for determining the boiling point at a given place is used.

Maximum and minimum thermometers.—It is often desirable to know the highest temperature reached since a thermometer was last read. For example, in weather reports it is usual to record the highest temperature reached during the day, and it is manifestly impracticable to watch the thermometer continuously with a view of determining this. By a simple device the thermometer itself can be made to record this reading. The arrangement by which this is accomplished constitutes a **maximum thermometer** (Fig. 208). In one kind of instrument there is introduced into the stem of the thermometer (before sealing it), above the mercury, a thin piece of iron wire which works loosely in the tube. When the mercury expands it pushes this piece of wire before it and on contracting leaves the wire at the highest place to which it has been pushed. The reading indicated by that end of the wire nearest to the mercury is the maximum temperature which has been reached. To set the thermometer again the piece of wire is drawn back to the mercury by the attraction of a magnet which hangs near the thermometer for this purpose. This is only one of many devices which have been suggested and used for this purpose ; the student should refer to one of the larger books on heat or meteorology for an account of the others.

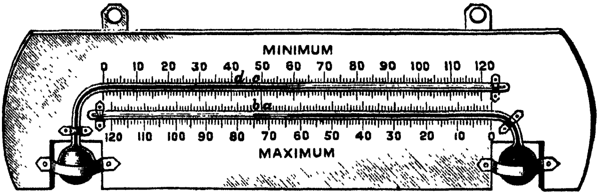


FIG. 208.—Maximum and minimum thermometers.

Similar arrangements have been devised for measuring the lowest temperature reached during the night or any other period. They are known as **minimum thermometers.** For measuring low temperatures it is general to use alcohol thermometers, and these can be made themselves to register the lowest temperature experienced. Into the stem of the thermometer a marker is introduced as with maximum thermometers, but the marker is of a different kind. It is either a fine capillary tube or a black index, shaped like a dumbbell. When the temperature falls the alcohol contracts, and the marker is dragged back with the liquid in consequence of the adhesion between the two materials. When the temperature rises again, the index remains stationary, the alcohol flowing round or through it according to the kind of marker, but not causing it to undergo any displacement. The end of the marker farthest away from the bulb will indicate the lowest temperature which has been reached.

The mean of the maximum and minimum temperatures of any one day is referred to shortly as the **mean temperature.** The average of such mean temperatures during any given period is called the **average mean temperature** for that period.

31. CONDITIONS AFFECTING VARIATIONS OF TEMPERATURE

1. Varying intensity of heat received from sun.—The angle at which the sun's rays strike any place on the earth varies, because

(*a*) the earth rotates on its axis,

(*b*) the earth's axis is inclined to the plane of its orbit, and

(*c*) the latitudes of places differ.

Which of the above reasons respectively give some explanation of the following facts?—(i) In January the average mean temperature of Tasmania (lat. 42° S.) is 60° F., while that of New York (lat. 42° N.) is 32° F.;

(ii) In July the average mean temperature of London (lat. 51° N.) is 64° F., while that of the Falkland Islands (lat. 51° S.) is 36° F.;

(iii) the temperature of a place is usually higher at midday than at sunset, although at sunset the place may have been exposed to several hours more sunshine than at midday;

(iv) it is always hotter in Madagascar than in the Kanin Peninsula (N. Russia) on the same meridian. Give reasons for each of your answers. In the cold weather in India which would you expect to be warmer—a hillside facing the south, or a neighbouring piece of ground sloping to the north? Would the same difference be found in higher latitudes, say, north of 45°, and also in similar latitudes south of the equator in winter time?

2. Proximity or otherwise to the ocean.—(*a*) Weigh out ½ lb. of dry gravel; put it in an air oven (Fig. 209) or a water oven, and keep the oven at the temperature of boiling water (p. 366) for half an hour. Have ready ½ lb. (8 fluid ounces) of boiling water, and also two beakers containing convenient equal quantities of cold water at any, though the same, temperature. Pour the half pound of boiling water into one beaker of cold water, and the half pound of hot gravel into the other. Stir each mixture and read the temperature with a thermometer. Which mixture attains the higher temperature? Which must have given out the greater amount of heat in cooling—the half pound of boiling water or the half pound of gravel at the same temperature? Will warm water or warm land at the same temperature be likely to give out more heat in cooling from summer to winter? Will a seaside or an inland place on the same latitude (other conditions being equal) be likely to have milder winters? Why?

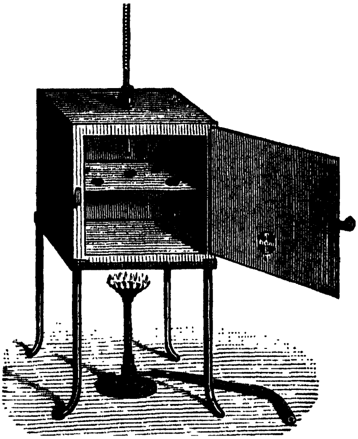


FIG. 209.—An air oven.

(*b*) In one beaker place ½ lb. of gravel, and in another ½ lb. of water at the same temperature. To each add the same quantity of boiling water, and mix. Which mixture reaches the higher temperature? Is water or gravel warmed less by the same amount of heat? Is a seaside or an inland place on the same latitude (other conditions being equal) likely to be hotter in summer? Why?

Are seaside or inland places, on the same latitude, likely to have the greater difference between their summer and winter temperatures? Why?

Why is water said to have a *high capacity for heat*?

(*c*) Give some explanation of the following facts:

(i) In January the average mean temperature of Vancouver Island is 36° F., while that of Winnipeg, on the same latitude, is 0° F.;

(ii) In January the average mean temperature of Mafeking is 90° F., while that of the west coast of Africa, on the same latitude, is 70° F.;

(iii) In July the coast of North California has an average mean temperature of 60° F., while Colorado, on the same latitude, has one of 90° F.;

(iv) The difference between the summer and winter temperatures of Verkhoyansk in Siberia is 116° F., while the range in the Lofoten Islands, on the same latitude, is 23° F.

(*d*) *Temperature of surface waters.*—Judging from the paths of the ocean currents (Fig. 194) alone, which of each pair of the following coasts do you suppose has the warmer surface waters *on the Tropic of Capricorn*: (i) East Africa or West Africa, (ii) West Africa or Brazil, (iii) Brazil or Chile, (iv) Chile or Queensland? Give reasons for your answers.

What is the difference in the latitudes of New York and the Shetland Isles? How do you account for the fact that the mean annual temperature *of the ocean surface* at both places is the same (50° F.)? What two currents are chiefly concerned? Where does each originate?

3. Presence of water vapour in the atmosphere.—Observe whether very cold days and nights of winter occur when the air is dry and the sky clear, or when the air is damp and the stars are hidden at night by clouds. Water vapour in the air is said to prevent the heat of the earth from escaping into space, as the glass of a greenhouse or "cold frame" prevents the heat inside from escaping. Observe the temperatures inside and outside greenhouses and "cold frames" at various times, and try to find out if the glass really acts in this manner. Why is a glass screen sometimes used in rooms to protect people from the direct heat of the fire?

4. Influence of rainfall.—(*a*) Notice whether the temperature in the cold weather or *winter* changes to any marked extent when rainy weather comes on. If so, does it rise or fall? Make similar observations in the hot weather and rains or *summer*; is there any obvious connection between temperature and wet weather in summer?

(*b*) Comment on the following temperature and rainfall records * at various Indian Hill Stations in January and July, 1936 :

Hill Station at altitude in feet above M.S.L.		Mean Temperatures in *January* 1936.		Rainfall in inches in *January* 1936.	Mean Temperatures in *July* 1936.		Rainfall in inches in *July* 1936.
		Max.	Min.		Max.	Min.	
	Feet.	°F.	°F.	Inches.	°F.	°F.	Inches.
1. Maymyo	3546	71·4	39·8	0	76·5	67·1	4·81
2. Haka	6100	61·4	40·7	0·16	70·2	60·7	8·56
3. Kanpetlet	6274	62·3	41·8	0	70·7	60·9	11·81
4. Shillong	4921	57·2	35·8	0.08	75·1	64·9	19·60
5. Cherrapunji	4309	57·6	43·0	0·72	71·5	65·7	104·64
6. Darjeeling	7432	43·4	33·0	0	65·5	58·5	33·50
7. Kalimpong	3913	57·3	44·9	0	75·1	67·7	27·13
8. Katmandu	4388	64·8	31·1	0	82·5	68·4	13·66
9. Muktesar	7592	49·2	32·6	0·27	67·1	56·3	29·44
10. Mussoorie	6940	48·9	34·2	0·59	68·1	60·3	31·27
11. Simla	7224	45·7	34·0	0·14	69·3	59·6	20·01
12. Murree	7115	41·9	28·7	3·27	72·8	60·6	8·79
13. Cherat	4272	48·1	37·2	2·19	89·7	71·1	1·13
14. Parachinar	5673	49·5	25·3	0·17	88·2	66·8	3·29
15. Drosh	4723	43·7	28·7	1·20	98·6	73·8	0
16. Mt. Abu	3945	64·7	47·3	0	73·9	60·5	8·06
17. Pachmarhi	3528	72·0	48·4	0·06	76·1	68·3	21·05
18. Mahableshwar	4534	74·4	56·9	0	65·3	62·7	52·39
19. Mercara	3781	77·7	57·7	0	67·9	62·7	44·82
20. Ootacamund	7364	65·8	42·1	0·19	61·3	51·8	6·70
21. Coonoor	5730	67·7	47·1	1·41	71·3	59·3	4·34
22. Kodaikanal	7688	63·2	46·3	0·22	62·4	52·4	6·07

How is the mean temperature for any day obtained?

Varying intensity of the heat received from the sun.—Some of the waves of heat, light, and other forms of energy travelling through space from the sun—which together constitute sunshine—come into contact with the earth's atmosphere. A small part of them is reflected by the upper layers of the atmosphere, but the greater number enter, and either are transmitted to the earth or are absorbed in their passage through the air. About one-half of the rays which enter the atmosphere, and are capable of being converted into heat energy, are absorbed in their passage, while the rest are transmitted, and, reaching the surface of the earth, are absorbed by it and warm it. The angle at which the sun's rays strike any given region of the earth determines their heating effect to a very great extent.

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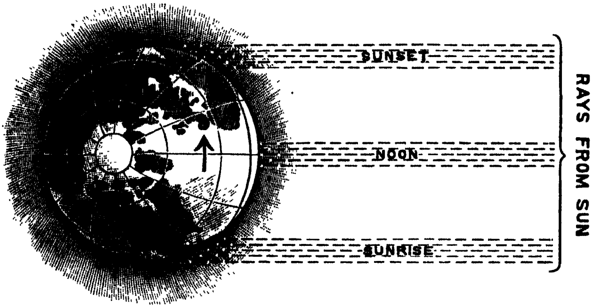
* From "India Weather Review", from Monthly Weather Reports for January and July, 1936, respectively. (Published by the authority of the Government of India.)

The **diurnal variation** of temperature at any given place may be explained in this manner. At sunrise and sunset the rays have to pass through a greater thickness of atmosphere than at noon, consequently more of their heat is absorbed by the air (Fig. 210). Moreover, the same bundle of noonday rays is also spread over larger surfaces at sunrise and sunset. Naturally, such a diurnal variation is least at the poles, where the sun shines continuously, or is below the horizon continuously, for six months. The difference between day and night temperatures is greater and greater as the poles are left behind, and reaches a maximum at the equator.



G. 210.—Showing the greater thickness of atmosphere passed through by the rays of the sun at sunrise and sunset than at noon.

The broad **differences between summer and winter temperatures** in any particular latitude are to be accounted for by the inclination of the earth's axis to the plane of the ecliptic (p. 122). As a result of this, the sun's rays strike the earth in the Ganges delta at an angle of 45° on December 21, and at an angle of 90° on June 21. In other words, on December 21 a given surface near Calcutta receives 70 per cent. of the heat it would receive on June 21, when the sun is overhead. The minimum temperature is reached about January 8-11; the maximum about July 14-16.

Again, the altitude of the sun varies in **different latitudes** (p. 123). The more nearly vertically the rays from the sun strike the earth, the less will be the extent of atmosphere traversed, and the larger will be the amount of heat radiation which reaches a given area of the earth during the day. The sun is most nearly vertical in equatorial region, and it is there, in general, that most heat will be received, the amount getting smaller as the poles are approached (Fig. 211).

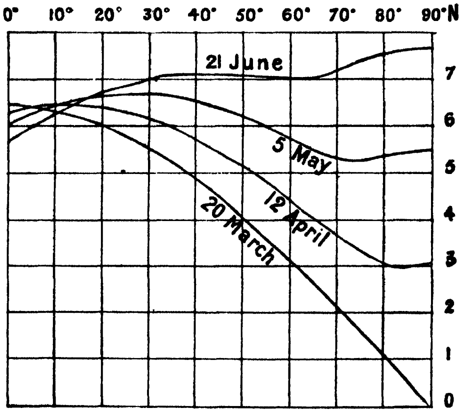


FIG. 211.—Relative amount of solar heat received at each latitude at various periods (after Wiener).

On the other hand, Fig. 211 also shows that, at midsummer, within the Arctic circle (lat. 66½° N.), the amount of heat received from the sun is greatest nearest the pole. The explanation is that the increased **length of the day** (p. 124) more than compensates for the greater weakness of the sunshine, which is caused by the obliquity of its rays.

A little thought will show that varying latitude must have precisely opposite effects upon *seasonal* variation and *diurnal* variation of temperature. Seasonal variation is least in equatorial regions—

where the amount of solar heat received differs but little in summer and winter—and is greatest at the poles (Fig. 211).

How the atmosphere is warmed.—Besides the heating of the atmosphere by those of the sun's rays which it directly intercepts, the air becomes warmed, firstly, by *contact* with the heated earth, and, secondly—since the earth continually radiates its own heat—the air becomes heated also by radiations from the earth. The heat rays which leave the earth in this second process are found to have undergone a complete change of character; they are no longer luminous, but belong entirely to the kind of radiation called *dark heat waves.* The atmosphere cannot transmit them as it could before, for, while the air is transparent to the luminous rays from the sun, it is more or less opaque to the dark radiations from the earth. A similar change in heat rays from the sun is brought about in a more marked degree by glass, a fact which is made use of in the construction of greenhouses.

Tyndall showed that air with aqueous vapour in it is nearly one hundred times more absorptive of dark heat rays than pure dry air.* In speaking on this point, he said in one of his lectures: "No doubt can exist of the extraordinary opacity of this substance to the rays of obscure heat; *particularly such rays as are emitted by the earth after being warmed by the sun.* Aqueous vapour is a blanket more necessary to the vegetable life of England than clothing is to man. Remove for a single summer night the aqueous vapour from the air which overspreads this country, and you would assuredly destroy every plant capable of being destroyed by a freezing temperature. The warmth of our fields and gardens would pour itself unrequited into space, and the sun would rise upon an island held fast in the iron grip of frost."

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* "From Tyndall's experiments there seemed to be a wide difference in absorption of heat between dry air and vapour—seventy times as much heat was stopped by the invisible vapour—but this was discovered by Magnus to be really due to a film of water which condenses on the apparatus—so that the absorption due to water vapour is found to be but little greater than dry air. It has, however, been shown that dry air instead of being nearly as diathermanous as hydrogen has a higher absorption than olefiant gas."

"The absorption of the solar rays in passing through a vertical clear atmosphere exerting a pressure of 29·92 barometric inches is such as to reduce the incident heat from 1 to 0·534. Both air and invisible water vapour are moderately good absorbers of heat—nearly equal—and the varying diathermancy of the atmosphere depends chiefly on the quantity of condensed vapour in it as well as on solid matter—dust, etc., suspended in it." (H. F. Blanford, "The Indian Meteorologist's Vade-mecum", 1877.)

Some of the consequences, both direct and indirect, of the absorptive influence of this aqueous vapour, or moisture of the atmosphere, are of the greatest interest. Among the direct consequences, those which result from an absence of water vapour in the air, as described in the above quotation, may be included. A realisation of such conditions occurs on the moon, where there is no atmospheric envelope, and consequently no water vapour, to prevent the radiation of heat, and the difference there, as a result, between the highest temperature of the lunar day and the lowest temperature of the lunar night must be immensely great.

An approximation to this condition of things may perhaps occur at various places on the earth's surface where the climate is arid and the air somewhat rarefied. The winters of Tibet, for instance, are, from the scarcity of water vapour in the clear air and consequent excessive radiation, exceedingly severe. Over the desert of Sahara, too, the warm air is exceedingly dry, so that when the days are intensely hot, they may be followed by exceedingly cold nights. After sunset, if there is little water vapour present to diminish the clearness of the air and so prevent a free radiation of heat, the temperature of the earth rapidly falls, often reaching the freezing point. The same thing is true of the central parts of the Rajputana desert.

There are few places where the air is absolutely dry. The apparently dry winds of a hot desert region often contain more water than the damp air, on a wet wintry day, in a cold climate. Cold winds will often feel dry as they descend from mountains, and it is not rare to see clouds disappear as they roll down mountain slopes. On the other hand, it is a familiar sight to see clouds increase as they ascend from the valleys. On the Hazaribagh plateau, the quantity of water in the air is sometimes as low as $\frac{1}{260}$ of the mass of the atmosphere, or about 1·7 grains per cubic foot of air ; but in the neighbourhood of the coast, during the rains, the moisture in the air occasionally exceeds $\frac{1}{50}$, or upwards of 11 grains per cubic foot of air. At 32° F. it requires 2·37 grains of water to saturate one cubic foot of air, at 50° F. the amount necessary is 4·28 grains, and at 70° F. about 8 grains of water per cubic foot of air.

Vertical variation of temperature.—Dr. Harold Jeffreys has stated (" Earthquakes & Mountains ", 1935, p. 114) that " Dry air can become unstable only if its temperature decreases with height at a rate exceeding 10° C. per kilometre. For air saturated with water vapour the rate is 6° C. per kilometre. When the ground is strongly heated a rising current of air is produced ; as it rises it cools under reduced pressure and may reach such a temperature that some of its water has to condense. On rising further more water separates, and the result is a cumulus cloud. This is the explanation of the large wool-pack clouds that are so prominent on hot days in summer."

It should now be clear why the air nearest to the earth is warmest, and why it is that as we ascend into the atmosphere the air becomes colder. This change of temperature with increase of altitude is spoken of as the vertical variation of temperature. Up to a height which varies with the time and latitude, but averages about 7 miles, the temperature falls fairly regularly—about 1° F. in 304 feet. Whilst investigating the upper air with balloons carrying self-recording instruments, M. L. Teisserenc de Bort found in 1899, and again in 1902, that at this height the temperature, having reached about −65° F., ceases to fall. In the belief that above 7 miles high the atmosphere is uniformly at −65° F., meteorologists have called this upper part the " isothermal region " or " stratosphere ", distinguishing the lower air as the " troposphere " because its temperature changes with height.

An unexpected and remarkable state of affairs has, however, been indicated by recent calculations based on the speed, brightness and length of path of meteors at altitudes inaccessible to balloons (p. 437). It seems that the temperature in temperate latitudes continues at about −65° F. at heights from 6 or 7 miles to about 34 miles ; but above 37 miles or thereabout the temperature appears to be much higher, and comparable with that at the earth's surface.*

Although **the average fall of temperature up to a height of about 7 miles is thus 1° F. for 304 feet,** the rate of decrease is not the same throughout. Gold showed that the rate up to 2 kilometres (1¼ miles) depended very considerably on the wind direction as well as on the time of the year, and results obtained from kite ascents have given the rate up to 3 kilometres as about 1° F. for 388 feet.

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* " The Uppermost Regions of the Earth's Atmosphere ", by Dr. G. M. B. Dobson (The Halley Lecture, 1926, Oxford University Press).

The vertical decrement in the dynamic cooling of the air in certain places in India is given below (after H. F. Blanford) :

Months	Darjeeling, 6941 ft. Goalpara, 386 ft.		Chakrata, 7051 ft. Roorkhi, 886 ft.		Murree, 7467 ft. Rawalpindi 1650 ft.		Pachmarhi, 3504 ft. Hoshangabad, 1020 ft.	
	Diff. of Temp. in °F.	Height per 1° F.	Diff. of Temp. in °F.	Height per 1° ft.	Diff. of Temp. in 1° F.	Height per 1° F.	Diff. of Temp. in 1° F.	Height per 1° F.
January -	21·5	305	16·0	385	9·9	586	9·1	273
February -	23·6	278	17·6	350	11·8	493	8·8	282
March -	23·2	282	20·3	304	12·5	460	8·6	289
April -	20·9	313	20·8	296	14·5	400	8·9	279
May - -	18·4	356	22·3	276	14·6	399	9·7	256
June - -	17·1	383	21·6	285	17·5	332	10·8	230
July - -	17·5	374	19·4	318	19·5	298	9·4	264
August -	17·8	368	19·6	314	17·8	326	9·3	267
September	18·4	356	19·9	310	13·8	420	9·2	270
October -	20·3	322	17·3	356	10·1	574	10·4	239
November	20·9	313	12·1	509	7·6	765	11·2	224
December -	21·2	309	12·5	493	6·6	880	9·2	270
Year -	20·1	330	18·3	350	13·0	494	9·5	262

It has been found repeatedly, however, that the mean temperature of the air in contact with a mountain is slightly below that at the same height in the free atmosphere. Theoretically, Calcutta air at 83° F. on a May morning would be cooled to 32° F. at 9100 feet, roughly 2000 feet above Darjeeling, but with normal standing air the temperature at Darjeeling is about 57° F., *i.e.* half that between the plains and melting ice. It would thus be necessary to go to nearly 15,000 feet before 32° F. becomes a fixed temperature in the Sikkim Himalaya. Calculations also suggest that half the moisture in the atmosphere lies below the altitude of 7000 feet (the height of Darjeeling) and that more than three-quarters is retained in the air below an elevation of 14,000 feet. On such computations it is evident that a mountain chain must be an effective barrier to the passage of water vapour, and we may conclude that the more elevated parts of the earth's surface are not so well protected—by the " blanket of aqueous vapour "—against loss of heat as are the more low-lying regions, and the chilled surface of the mountain naturally affects the temperature of the air in contact with it.

It is common knowledge that in hot countries like the plains and peninsular of India climate is modified by height above the sea level and it is for this reason customary for those who can afford to do so to retire to places on the hills during the hot seasons, because of the more bearable conditions experienced there.

It is also interesting to note that the same gradations in the character of the vegetation remarked in travelling from the equator to the poles are also to be observed in ascending almost any sufficiently high mountain in the tropics. In the valleys of the Sikkim Himalaya a profusion of tropical plants abounds, while at the elevation of Darjeeling pines and rhododendrons are common, and on the lower slopes of Kanchenjanga, about the snow line, the only evidences of vegetation to be discovered are specimens of Arctic (or " Alpine ") plants such as are found in the polar regions. This is true for the Kumaon Himalaya also, but in the peninsula and the Assam ranges, where the snow line is not reached and the flora of the plains is luxuriantly tropical, the intermediate journey is through a region which can be divided into zones of vegetation precisely similar to those of middle latitudes (Chapter XVI).

Temperature modified by proximity to the ocean.—Countless experiments, essentially of the nature of Expts. 2, (*a*) and (*b*), p. 369, but made with all the refinements necessary to avoid error, have proved that water requires more heat than any other substance to raise its temperature through a given range ; and on the other hand that, in cooling from one given temperature to another, water gives out more heat than any other substance. This is expressed concisely by saying that water has a greater capacity for heat, or has a greater **specific heat,** than any other substance. As a consequence the same exposure to the sunshine does not make the water of the ocean so warm as the neighbouring land in summer ; and, conversely, an equal loss of heat in the winter does not cool the ocean, and the air overlying it, so much as it cools the neighbouring land and the air just above the land. The high specific heat of water, therefore, is instrumental in bringing about a marked **uniformity in the climates of islands.** Surrounded as they are by water, they experience a small annual range of temperature only, which in the case of some islands in the tropics amount to no more than four or five degrees. A small range of temperatures is one of the characteristics of an **oceanic climate.** Though the uniformity in the case of larger islands in temperate zones is not so pronounced, it is still considerable compared with the difference between the extreme winter and summer temperatures of places far removed from the coast of the nearest ocean. Places of this character, like Great Britain or Tasmania, are said to have an **insular climate,** while inland stations like Moscow experience what is called a **continental climate.** Verkhoyansk in Siberia and the Lofoten Islands are both situated in the same latitude ; but while the annual range in the latter place is only 23° F., in the former it is as much as 116° F. The mean temperature of Bombay, on the coast, varies from 73° F., to about 83° F.; while that of Nagpur, in the middle of the peninsula, ranges from 73° F. to 100° F. These towns differ in position as regards their latitude by only a few degrees. A fuller classification of climates is given in Chapter XV.

Distribution of ocean temperature.—The temperature of the ocean water at various depths is determined by using a self-registering thermometer, constructed to bear the immense pressure it is subjected to when sunk. It will be sufficient here to enumerate simply the chief results of the work of various expeditions, such as that of the *Challenger*. The **temperature of the surface waters** of the ocean varies fairly regularly with the latitude and the time of the year. It is greatest in the tropics, where it sometimes reaches a temperature of 86° F., as at places a little north of the equator ; but, speaking generally, it can be said to vary from 60° to 80° F. The temperature falls as the poles are approached, until a temperature slightly below the freezing point of pure water has been reached well within the Arctic Circle.

Although the temperature of the surface waters thus varies, in a general sense, with the latitude, it is affected naturally by *ocean currents*, since many streams and drifts distribute warm tropical waters northward and southward, and certain other currents carry cold Arctic and Antarctic waters to regions of middle latitudes. The Gulf Stream drift and the Labrador current (p. 337) are, for example, responsible respectively for the fact that the average *ocean* surface temperature is the same (50° F.) at New York (lat. 41° 6′ N.) and the Shetland Isles (lat. 60° 30′ N.) ; and similar, though less marked, departures from the general rule are noticeable in other parts of the world.

The difference between the highest summer temperature and the lowest winter temperature of the surface water is greatest in the temperate zones, where it is as much as 10° F., while this difference is least near the equator and poles. The daily variation of temperature is insignificant, rarely being more than 1° F. It is least about sunrise, and reaches a maximum about 4 p.m. This constancy in the temperature results chiefly from two familiar properties of water, (*a*) its high specific heat (p. 378) and (*b*) its slight power of conducting heat. As a consequence of its high specific heat, water requires a

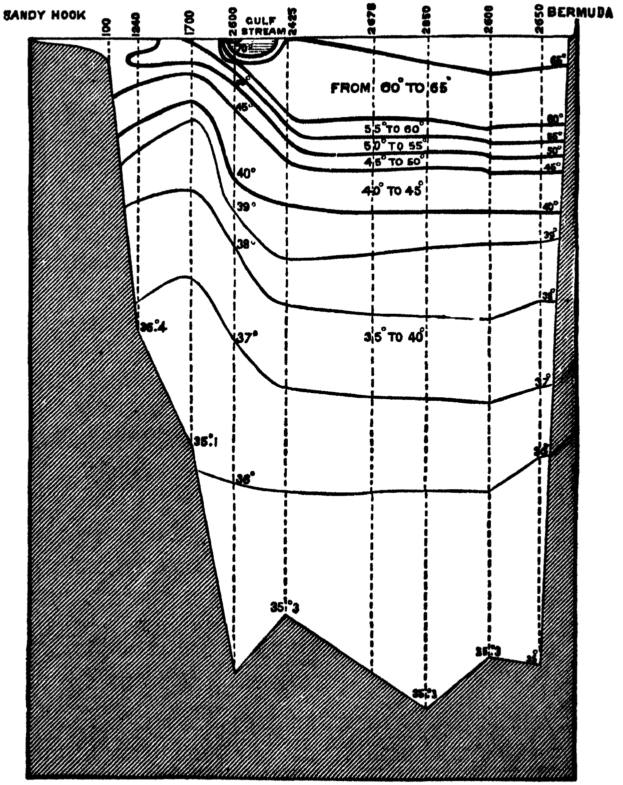

FIG. 212.—Section of the Atlantic Ocean between Sandy Hook (New York) and Bermuda. Dotted lines show depths; the others are lines of equal temperature.

large amount of heat in order to warm it, but once having its temperature raised, it cools again with a corresponding difficulty.

The poor conducting power of water explains what has been noticed everywhere throughout the oceans, *viz.* that the heat from the surface water does not spread throughout its mass. A glance at Fig. 212 will show that the **temperature of the ocean water at a comparatively small depth** is very much lower than at the surface. At a depth of a little over half a mile, a temperature of 40° F. is reached, and the temperature gets very little lower from this depth to the bottom, for the lowest reading of the thermometer in Fig. 201 at a depth of 2650 fathoms is 35° F. The same fact is brought out in the table seen below. **In the Mediterranean Sea,** on the other hand, the temperature remains 55° F. from 190 fathoms to the bottom (greatest depth 2406 fathoms), because *the ridge at the Strait of Gibraltar excludes all the cold Atlantic waters below* 190 *fathoms.*

Similarly, owing to the ridge, less than 200 fathoms deep, at the Straits of Bab-el-Mandeb at the entrance to the Gulf of Aden, the waters in the Red Sea, although more than 1200 fathoms in depth, have a uniform temperature, at 70° F., from 200 fathoms below the surface to the floor. Within 200 fathoms of the surface the water temperature varies and may be as high as 85° F. at the surface in the hot season. In the adjoining Gulf of Aden, which is deeper than 1200 fathoms, the temperature is found to decrease with depth and is about 37° F. at 1200 fathoms (Hugh Robert Mill, *The Realm of Nature,* 1932, p. 191).

THE MEAN TEMPERATURES FOR ALL THE OCEANS AT DIFFERENT LEVELS

Depth in fathoms	Temperature °F.	Depth in fathoms	Temperature °F.
100	60·7	900	36·8
200	50·1	1000	36·5
300	44·7	1100	36·1
400	41·8	1200	35·8
500	40·1	1300	35·6
600	39·0	1400	55·4
700	38·1	1500	35·2
800	37·3	2200	35·2

Other conditions affecting temperature.—The range of temperature is influenced directly by the **prevailing winds** (Chapter XIV). For instance, the winds which blow for the greater part of the year in the

Sahara, coming from the higher latitudes of Europe, are felt as cold, dry winds, and do much toward lowering the temperature of this desert. Or, taking the case of the Indian peninsula, the west and south-westerly winds, arriving after a journey over the Arabian Sea, where they have become warmed and saturated with moisture, are powerful agents in causing a mild climate on the west coast of this country; whereas, the easterly and north-easterly winds coming partly across the Bay of Bengal to the Coromandel coast also carry moisture and, while they prevail, bring about wet conditions in the Madras Presidency from October to December.

Indirectly also, the early cold weather or winter temperatures of the Madras uplands are dependent to a remarkable extent on the prevailing east and north-easterly winds, because these winds are laden with so much moisture which is thrown down as **rain.** When rain falls on a cold day the temperature rises (p. 371), for the wind bringing the water vapour which is condensed as rain must necessarily be warmer than the place where the rain is formed (Chap. XIII). The rise of temperature is naturally less noticeable on an already warm summer day than in winter, and may indeed be quite neutralised by the cooling which accompanies rapid evaporation from the wet, warm ground. The consequence is that in winter the most rainy districts are in general the warmest. In the dry, warm weather period the broad distribution of Indian temperatures has no obvious relationship to the rainfall, in spite of the fact that the prevailing winds are still south-westerly.

In certain areas the temperature may be influenced also by such causes as **the slope of the ground**; should the inclination be in the direction of the midday sun the amount of warming experienced will be greater than in those cases where the slope is towards the rising or setting sun. Thus, it is probable that owing to the general southerly slope from the Satpura highlands to the Nagpur plains this area may be exposed to greater heating by the sun than will occur on the steeper slopes of the Western Ghats which face the sea in a westward direction.

The influence of oceanic currents is also often instrumental in producing variations of climate. The hot weather climate of the Konkan and the coastlands of Malabar are made cooler by the southerly current of water and the north-westerly winds blowing from the Arabian Sea; while warmer monsoon currents, during the rains, result in a contrary effect. The coast of Italian Somaliland,

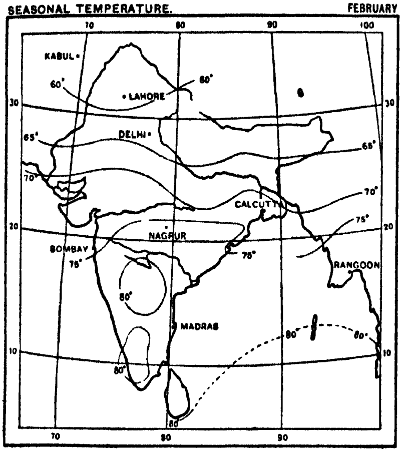

FIG. 213.

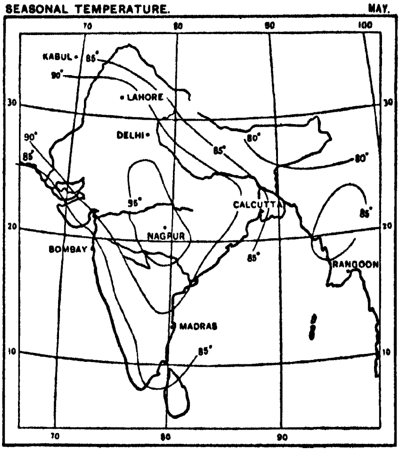

FIG. 214.

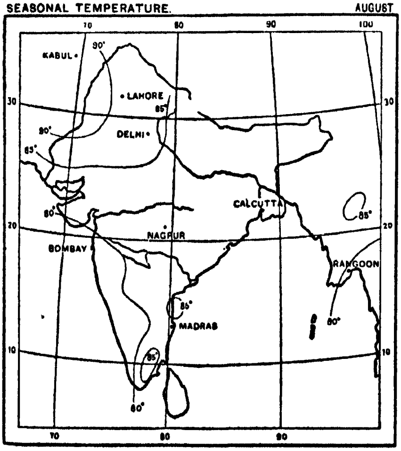

FIG. 215.

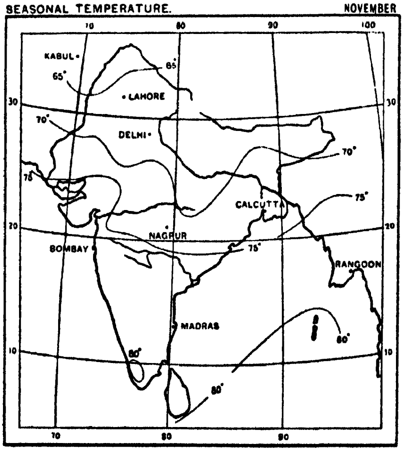

FIG. 216.

and East Africa partly, is cooled by the coastal up-welling current of cold water during the height of the Indian south-west monsoon, because the winds over it blow off-shore. This cold rising ocean current off the African coast renders the Arabian Sea there too cold for coral growth and explains its absence. Off the Malabar coast the waters of the Arabian Sea are warm and corals flourish, as seen in the atolls of the Laccadive and Maldive archipelagoes.

Cultivation results in modifications of climate. The clearing of forest land, which up to a certain point is productive of an increase of temperature and a beneficial diminution of the moisture, may, if carried too far, lead to increased evaporation, and therefore loss of moisture, and thus seriously diminish the productiveness of a country. The extensive draining of a marshy district has been known in several instances to result in an increase of its mean annual temperature. Similarly the water-logging that often results from over-irrigation in India may help to lower the mean temperature of the area, but this does not, unfortunately, compensate for the greater unhealthiness that generally follows.

32. ISOTHERMS

1. The meaning of the word isotherm.—Assume that at 9 a.m. on Jan. 14, 1936, each of the following towns had a temperature of 70° F.: Mandalay, Akyab, Vizagapatam, Nagpur, Poona, Surat, Jodhpur, and Karachi; mark these places on an outline map of British India and connect them by a smoothly curved line. The line is the isotherm of 70° F. for the hour in question. Define the term *isotherm.*

2. To draw the May isotherms.—The following are the average mean May temperatures * of the places named below. Mark each place on an outline map of British India, with its temperature, and then join with a smoothly curved line all places having the same temperature.

80° F.: Jalpaiguri, Goalpara, Gauhati, Lumding, Digboi.

85° F.: Kabul, Murree, Kalka, Dehra Dun, Naini Tal, Monghyr, Calcutta, Colombo, Tuticorin, Shimoga, Belgaum, Poona, Surat, Nawanagar, Karachi, and also

85° F.: continued in Burma: Arakan, Henzada, Kalaw, Lashio, Bhamo, Tawmaw (Jade mines), Homalin, Kalewa, Akyab.

90° F.: Ghazni, Kohat, Jhelum, Lahore, Meerut, Lucknow, Benares, Patna, Dhanbad, Sambalpur, Bezwada, Cuddapah, Bellary, Satara, Manmad, Ahmedabad, Sukkur, Quetta. Also an isolated record from Mandalay.

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* *I.e.* the average of the mean daily temperatures (p. 386) of the place during July.

95° F. : Bikaner, Jhansi, Damoh, Jabalpur, Bilaspur, Jeypore (Orissa), Hyderabad (Deccan), Akola, Burhanpur, Bhopal, Gwalior, Jodhpur, Sibi, Dera Ismail Khan, Mianwali, Bhawalpur, Jaisalmer.

100° F. : An isolated reading at Hoshangabad, and other records from Amraoti, Chanda, Warangal, Jagdalpur (Bastar), Bhandara, Balaghat and Nagpur ; also one record from Jacobabad.

Compare the map with Fig. 214.

Estimate from these isotherms the probable average mean May temperatures of Porbandar, Bombay, Bangalore, Madras, Puri, Chittagong, Dacca, Ranchi, Agra, and Delhi.

3. To draw the January isotherms.—In an examination each candidate will be provided with an outline map of British India, on which are marked towns which are given in the daily weather reports in *The Statesman* during the month of January. Candidates will be asked to draw upon the map the isotherms for 60°, 65°, 70°, 75° and 80° F. and to explain the course which they take.

Mark the places and temperatures on an outline map, and draw the isotherms in the manner explained for contour lines on p. 44. First put in the 60° F. isotherm which roughly follows the line of 32° latitude, noticing that it will pass between the Simla hills and the Punjab Salt Range, between Peshawar and Bannu, and through Waziristan into Afghanistan.

In the Deccan and again in the Nilgiri hills the *80*° F. isotherm is a separate *closed* curve. Observe also that the 65°, 70° and 75° isotherms follow courses almost coincident with latitudes 26°, 23° and 20° respectively.

4. Study of isotherm maps of British India.—(*a*) *February isotherms.*— To which of the factors modifying temperature (considered in Sec. **31**) are the following facts shown on Fig. 213 respectively to be attributed?

(i) The general direction of the isotherms is from west to east ; in other words, the temperature decreases from south to north.

(ii) The isotherms bend to the north as they cross the land, and dip to the south as they cross the sea ; in other words, the summer temperature along any latitude is lower over the sea than over the land.

(iii) The highest temperature is found in the Deccan and also in the Coimbatore district, the isotherms of 80° F. forming concentric curves round each of these areas.

Which *inland* part of *western* India is least likely to be affected by the prevailing (westerly and south-westerly) winds?

(*b*) *May iostherms.*—Study Fig. 214.

(i) How does the direction of the 90° F. isotherm in the Indian peninsula agree with the direction of a *generalised* rectangular region which lies between the Himalayas and the east and west coasts?

How do you account for the facts?

(*c*) *August isotherms.*—Compare the diagram, Fig. 215, showing the isotherms for the wet, or south-west monsoon, period, with the rainfall map, Fig. 234, for June to October, and notice the coincidence of high rainfall with lower temperatures in southern India, and the low rainfall and higher temperatures in north-western India. Notice the same characteristics in Upper Burma.

(*d*) *Mean annual isotherms.*—How would you determine the mean annual temperature of a place? Study Fig. 221. To what extent do the mean annual isotherms combine the features of the mean January and July isotherms? What evidences does the map show of the influence of prevailing winds?

5. Study of isotherm maps of the world.—(*a*) *Summer and winter isotherms.*—Examine Figs. 218 and 219.

(i) Find in each case the area in which the average mean temperature is above 80° F. Describe the distribution of this area in January; is it chiefly north or south of the equator? Why? Describe its distribution in July; is it chiefly north or south of the equator? Why?

(ii) Where do the hottest regions extend furthest from the equator in July? Why?

(iii) Where do the coldest regions approach the equator most nearly in January? Why?

(iv) Trace round the earth on both maps the isotherms which pass through the British Isles. Where and when do they depart most from an east and west direction? Does Fig. 215 suggest any explanation of this?

(*b*) *Mean annual isotherms.*—Study Fig. 221.

(i) Are the areas of more than 80° F. chiefly on land or over the ocean? Why?

(ii) In what part of the world is the mean annual temperature gradient between 60° F. and 10° F. greatest? Why? In what part of the world is the mean annual temperature gradient between 60° F. and 10° F. least? Why?

(iii) Is there more land within the Arctic or the Antarctic circle? In which is the mean annual temperature higher? Why?

Isotherms.—If we draw lines on a map through those places which have the same corrected * lower air temperature at any given time, we are able to form an idea of the *horizontal* distribution of temperature, that is, the distribution of temperature of the air at the earth's surface at the time. Such lines are called " lines of equal temperature ", isothermal lines, or **isotherms.**

Isothermal surfaces.—A **surface** connecting all points having the same temperature is called an *isothermal surface.* Plainly the isothermal surface of 80° F. will cut the sea level along the isothermal *line* of 80° F., but it will rise above the surface of those parts of the earth which are warmer than 80° F. (p. 383), and will be below the surface of those parts which have a surface temperature below 80° F.

Isotherms may evidently be drawn to show the horizontal distribution of temperatures at any given hour, or the horizontal distribution of the mean (*i.e.* the mean of minimum and maximum) temperature for any given day, or of the average of such mean daily temperatures for any given month, or year, or number of years. In regions over which the temperature varies considerably between neighbouring places, the isotherms naturally lie closer together than where the temperature is more uniform, just as contour lines on a map lie closest together where the gradient is greatest. Indeed the term **temperature gradient,** suggested by this analogy, is often used to indicate the " rate " (measured, say, in degrees of temperature per 100 miles) at which the temperature alters along any given line ; and just as the direction of greatest slope (*e.g.* the path of a stream) on inclined ground crosses contour lines at right angles, so the line of greatest temperature gradient crosses isotherms at right angles.

Isotherm maps display in a striking manner the modification of temperature caused by such circumstances as varying season, latitude, proximity to the ocean, direction of prevailing winds, etc., considered in Section **31.** The crust of the earth, moreover, is made up of different materials, with varying specific heats and divers degrees of conducting power, and these are consequently warmed to different extents and the contiguous atmosphere participates in the same variations.

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* *I.e.* " reduced to sea level " by allowing for the effect (p. 376) of altitude upon temperature.

Isotherms of British India.—A comparison of the isotherms of British India for January or February and July or August shows very clearly that, unlike the British Isles, the Indian cold weather or **winter** temperatures do not depend on the heat liberated in the formation of rain. The temperature gradient is, therefore, seldom in the same general direction as the rain-bearing winds, *i.e.* from north to north-east. Comparisons of Figs. 213 and 215 show it to be broadly true that, except for Ceylon and South India, our lowest winter temperatures are found in districts of heaviest winter rainfall, and *vice-versa*. In the rains, or **summer**, on the other hand, the effect of the varying intensity of the sunshine at different latitudes is considerably neutralised in the peninsular region, either by the rainfall or by other circumstances, so that the summer isotherms run roughly parallel to the coasts and to the Himalayas. Local departures from the general directions just mentioned are interesting and suggestive. In Burma the hot weather isotherms are highest where the rainfall is least. This, as already pointed out, is similar to the Indian continental areas and dissimilar to the insular conditions of Ceylon and of the British Isles.

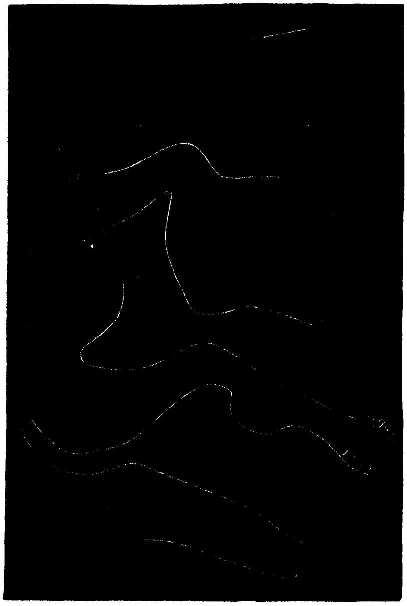


FIG. 217.—Mean annual isotherms for the British Isles.

In Hyderabad (Deccan) and part of Mysore a continental climate is in evidence, but, as the winter (cold weather) rainfall is trifling and the seasonal temperature high, it is impossible to draw general conclusions from the data obtained in such areas.

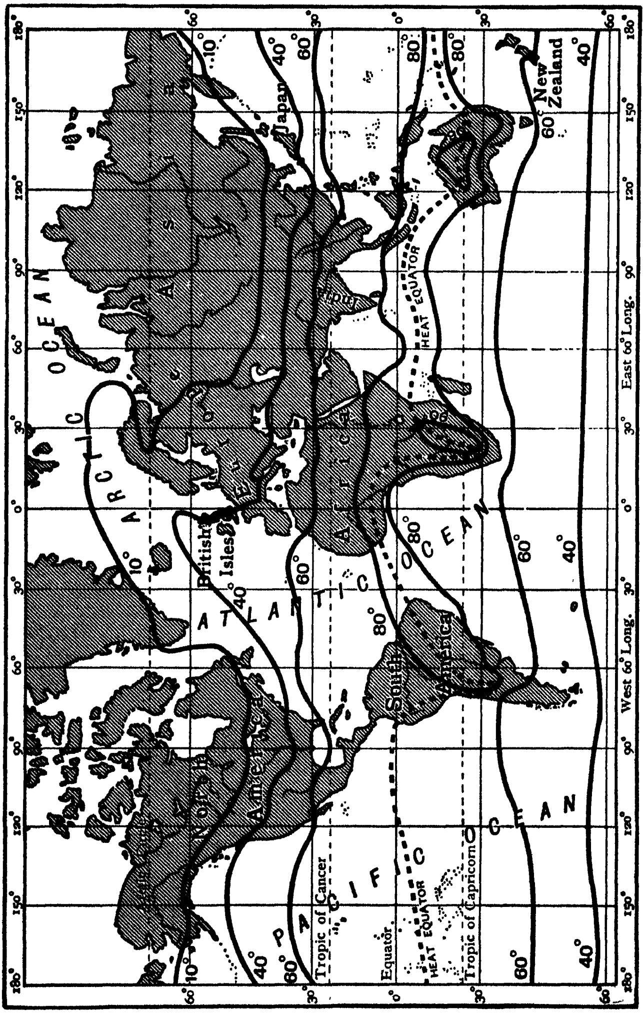
Isotherms of the world.—The same principles find an equally instructive application in the study of isotherm maps of the world. In **January** (Fig. 218) the hottest belt of the world lies somewhat to the south of the equator, as a consequence of the inclination of the earth's axis; within this belt the highest temperatures are found naturally on the land masses rather than over the sea. The **heat equator** (the line joining the hottest places on successive meridians) * consequently lies almost entirely to the south of the geographical equator in our winter, dipping most markedly south over South America, Africa and Australasia. The isotherms are broadly parallel to the parallels of latitude. In general, they take the form of wavy lines, which at this time of the year bend to the north as they cross the great oceans, and to the south as they cross the continents. This behaviour, of course, indicates that in the northern hemisphere (where it is winter) the air over the oceans is warmer than that over the land; and that in the southern hemisphere (where it is summer) the air over the oceans is cooler than that over the land. In the N.E. Atlantic the northward indentation of the winter isotherms is especially marked, as a result of the prevailing south-westerly warm winds. The curious distribution of winter temperatures in the British Isles is merely the local expression of a phenomenon affecting the whole of western Europe, and giving rise also to a great difference in the temperatures of the east and west shores of the Atlantic.

The January isotherms are noticeably closer together in the northern hemisphere than in the southern; in other words, the temperature falls off more rapidly towards the north pole than towards the south pole. This is partly because in the winter the north pole is turned away from the sun, and partly because there is more land in the northern hemisphere than in the southern.

In summer the rays of the sun shine more directly upon the northern than upon the southern hemisphere, and the results are displayed graphically by a map of the July isotherms (Fig. 219). The hottest belt has migrated northward, and the heat equator now lies almost wholly to the north of the geographical equator, making excursions northward as it crosses the great land masses. The northern isotherms are spaced more widely, and curve more or less to the north over the great land masses; the southern isotherms still dip from north-west to south-east on crossing the continents, indicating the relatively low temperature of the west coasts. Crossing the oceans, the July isotherms of the temperate zones run more nearly parallel to the lines of latitude than is the case in January. No sign is now to be seen of the great embayment of the isotherms over the N.E. Atlantic, since the prevailing winds here affect the summer temperature much less than the winter.

* It should be noted that the heat equator is not an isotherm.

Range of temperature.—The amount by which the temperature of a place varies throughout the year is a very important factor in



Emery Walker sc.

FIG. 218.—Mean January isotherms of the world.

determining climate. From Fig. 220, or from a comparison of maps of summer and winter isotherms, it is clear that the Torrid Zone is on the whole a region of moderate annual range of temperature, while the North Temperate Zone has extreme variations as compared with the South Temperate Zone, and the northern hemisphere has on the whole greater ranges than the southern. The reason for

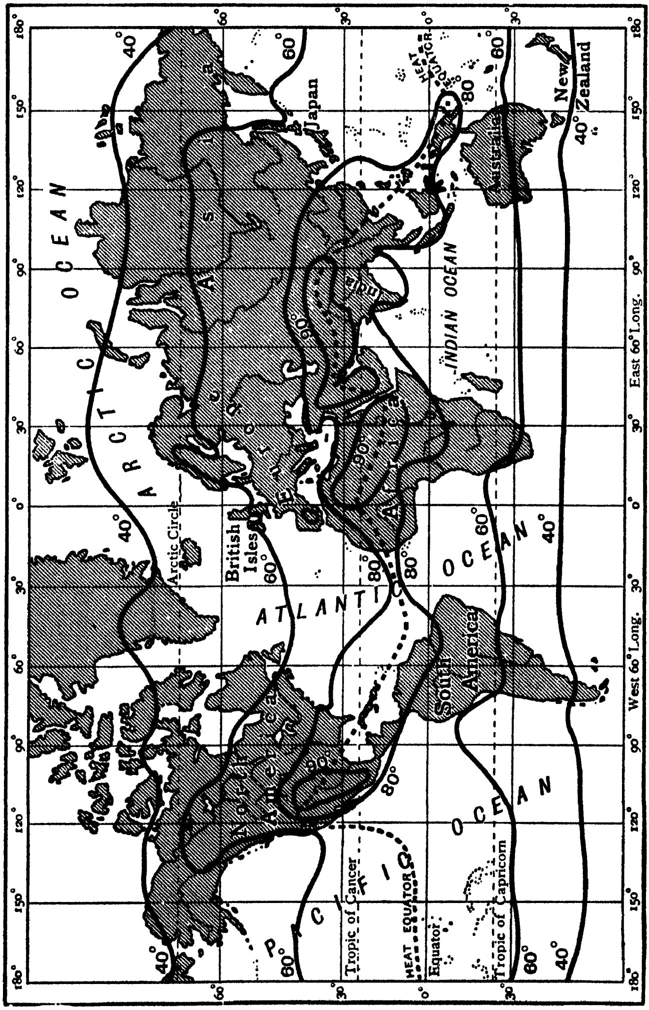


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FIG. 219.—Mean July isotherms of the world.

this is that water areas vary little in temperature during the year, while land areas change their temperatures much more readily. The effect of great land areas in producing large ranges of temperature is very evident. In northern Asia there is a range of 120° F.; in northern North America, 80° F.; in northern Africa, Australia, South Africa, and southern South America, 30° F. Another noteworthy feature is the small temperature range on the west side of continents in temperate zones.

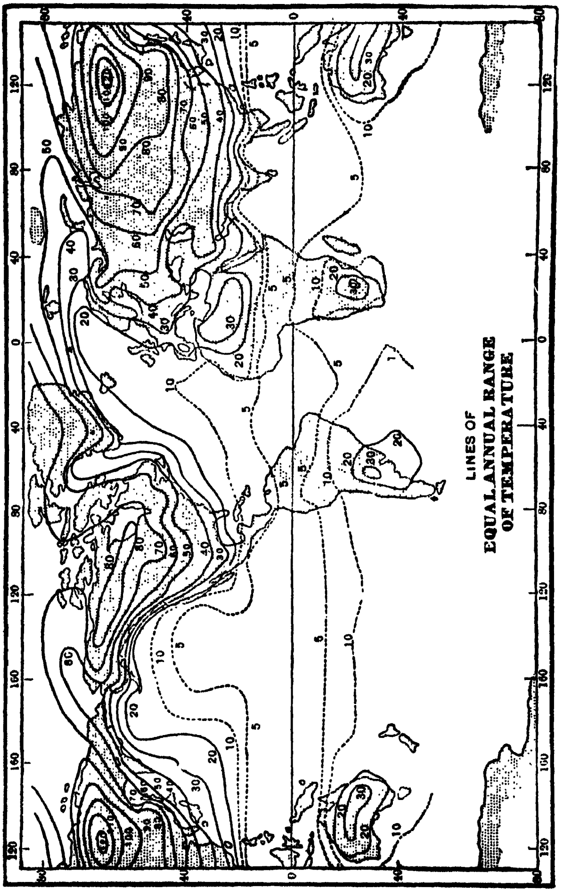
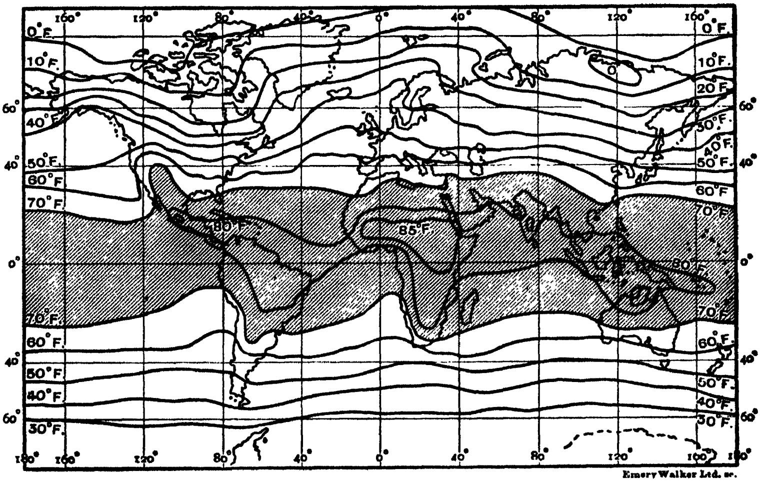


FIG. 220.—Lines of equal annual range of temperature. The number appended to the lines indicate the range in degrees Fahrenheit.

Mean annual isotherms of the world.—An examination of Fig. 221 (as of Fig. 217) shows that the mean annual isothermal lines follow paths which indicate to a large extent a compromise between the extreme conditions encountered in January and July. Fig. 221 also emphasises general facts which the variation from winter to summer tends to obscure. The map shows, for example, that the temperature gradient is in general steeper and more irregular over the northern than over the southern continents; so that, even though the mean position of the heat equator is somewhat to the north of the geographical equator, certain countries in the North Temperate and Arctic zones are decidedly colder, though these zones regarded as a whole are warmer,* than southern regions of corresponding distance from the equator. The map shows, too, that the influence of the prevailing winds—as exemplified by the temperatures of the North Atlantic and of the coasts of South America and Africa—is not of merely temporary importance, but has a marked effect upon general climate.



Emery Walker Ltd. sc.

FIG. 221.—Mean annual isotherms for the world.
The belt of temperatures above 70° F. is shaded.

It ought to be mentioned that although the influences affecting temperature-distribution which have been considered in this chapter account satisfactorily for the broad facts, the subject is complicated by various other circumstances having a more or less temporary or local significance. Thus, it has of late years been pointed out that certain disturbances of the atmosphere in one part will produce opposite conditions in another. For instance, an unusually high summer temperature in the Arctic seas will set free a large amount of ice, and the polar current, arriving later at Iceland and the North Sea, will lower the temperature of those regions to an exceptional extent.

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* Compare Fig. 126.

EXERCISES ON CHAPTER XII

1. What is meant by isothermal lines? Why do they vary in their direction at different seasons of the year? Illustrate your answer by a particular example.

2. What part of India has the highest average temperature (*a*) in January, (*b*) in July? In each case give a reason.

3. What is an isotherm? Show why it does not coincide in direction with a parallel of latitude, and why it varies its position during the year.

4. Describe the average distribution of temperature in India and Burma during the winter months, pointing out how it differs from the distribution during the summer. Account for the facts.

5. Temperature is regulated by latitude. Criticise this statement, using well-marked climatic regions of Europe and Asia for purposes of illustration.

6. On what parts of the coasts of the British Isles would you expect to find (*a*) a mild climate in winter, (*b*) a cool climate in summer? Give reasons for your answers.

7. Describe and explain the use of the maximum and minimum thermometer. At what hours would you expect to find the temperature at its maximum and its minimum respectively?

8. What are the principal causes which affect the temperature of a district?

9. Describe as exactly as you can the direction taken in Asia and Europe by the January isotherm of 32° F. Compare this with the January isotherm of 60° F. What might you deduce from these facts alone as to the commercial value of some of the rivers of Europe?

10. From the following data draw on squared paper three curves showing the maximum, minimum and mean temperatures.

Date	Max. Temp.	Min. Temp.
Nov. 1	52° F.	48° F.
„ 2	54°	48°
„ 3	51°	48°
„ 4	53°	47°
„ 5	50°	40°
„ 6	48°	38°
„ 7	47°	36°

11. Draw a curve showing the rise and fall of the thermometer in two localities for a fortnight in November—one on the coast of India and the other within the peninsula—on about the same latitude. The data may be taken from the daily weather reports published in the newspapers, *e.g. The Statesman.*

12. What are isothermal lines? Describe how to find isothermal lines for your lecture room.

How do you account for the different temperatures in different parts of the room?

13. On a blank map of India draw boldly three or four isothermal lines for January; in another colour draw three or four for July. Explain in writing any great difference in their general direction. Give reasons for this difference.

14. Make a comparison of the distribution of the isotherms on the map of the world. Show January and July isotherms, and explain the movement of the regions of highest temperature throughout the year.

15. The annual range of temperature in tropical Africa is small. Account fully for this.

16. Give an account of the ocean currents of the Indian Ocean, including the Bay of Bengal and the Arabian Sea, and discuss to what extent they influence the climates of adjacent coasts. Discuss the currents in the North Atlantic in a similar manner.

17. Describe and account for the distribution of temperature over the British Isles in summer and in winter respectively.

18. Describe the changes of temperature encountered in passing from the surface to the bottom of the sea (*a*) in the Atlantic, (*b*) in the Mediterranean, and (*c*) in the Red Sea. Account for the differences in these cases

19. What is the difference between the sea water at the surface and at the bottom of the Red Sea as regards saltness and temperature? Does the Gulf of Aden differ from the Bay of Bengal or the Arabian Sea in these respects, and if so, how and why?

20. Contrast the distribution of temperature over Upper Burma in winter with that in summer, and give reasons for the facts.

21. Explain fully the meaning of *three* of the following terms: isothermal lines, escarpment, cyclone, stratification, fault lines, cañon.

22. What are isothermal lines? Explain as fully as you can the reason why, in the British Isles, they do not coincide with parallels of latitude, while they often do so in India.

23. Contrast the distribution of temperature in the open ocean with that in the Mediterranean. Account for the differences.

24. The average temperature in May at Karachi is approximately the same as that of Colombo; whereas in February it is 7° lower. Account as fully as you can for these facts. In what parts of India and Burma are the most extreme and the most equable climates to be found?

25. What are the more important facts about the climate of the British Isles which are illustrated by the following figures:

	Temperature in °F.			
Place	January	April	July	October
Ben Nevis (summit) - -	24·1	27·6	41·1	31·4
Cambridge - - - - -	37·6	46·7	61·9	49·4
Valencia (S.W. Ireland) -	44·4	48·0	58·8	51·5
Deerness (Orkney) - -	39·0	42·3	53·5	46·9

Give four Indian examples to show these characteristics.

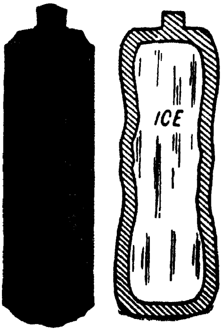
CHAPTER XIII

THE FORMS OF WATER

33. SOME CHANGES PRODUCED IN WATER BY HEAT

1. **Expansion of water on freezing.**—Repeat Expt. 2 on p. 295, using a cast-iron bottle full of water. The screw-stopper is tightly fixed with a spanner and the bottle is covered with a freezing mixture of three parts of ice to one of salt. After a short time, the bottle will be heard to crack and ice will be found inside it (Fig. 221A).

This experiment shows that water expands when it freezes. In this respect water behaves differently from most other liquids, which, when cooled, continue to contract down to their freezing points.



(i) (ii)

FIG. 221A.

(i) A cast-iron bottle.
(ii) The bottle burst by the expansion of water on freezing.

2. **Melting point of ice.**—Put some small pieces or shavings of clean ice into a beaker and insert a thermometer into them. Record the temperature indicated. Pour in a little water, stir the mixture, and again record the temperature. Place the beaker on a sand-bath and warm it gently. Notice the reading of the thermometer *so long as there is any ice unmelted.* In all these cases the reading of the thermometer is practically the same, indicating that the temperature of melting ice is constant.

3. **Heat required to melt ice.**—(*a*) Let a few lumps of ice stand in a beaker until some have melted. Notice that the temperature is 0° C. Counterpoise two empty beakers of the same size in the pans of a

balance, and put a small lump of ice into one, and the same weight of water from the melted ice in the other. You have thus equal weights of ice and water at 0° C. Pour equal weights of hot water into the two beakers. When the ice is melted, observe the temperature of the water in each beaker. The temperature of the water in the beaker in which the ice was placed will be found much lower than that of the water in the other beaker, because the ice uses up a large quantity of the heat in melting into water.

(*b*) Take equal weights of hot water in two large beakers of the same size. Place a piece of ice in one of the beakers, and observe the temperature of the water when it has melted. Pour ice-cold water into the other beaker until the same temperature is reached. Find, by weighing, the weights of ice and ice-cold water which have been added. It will be found that a small weight of ice has as much cooling effect as a large weight of ice-cold water.

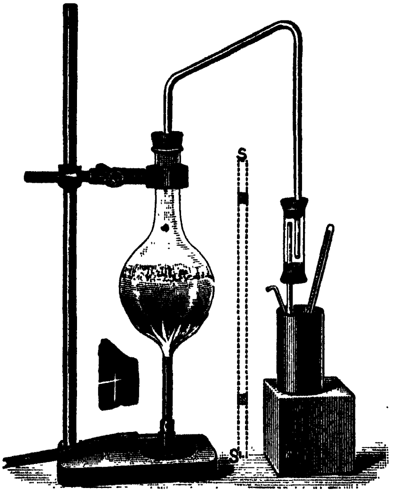


FIG. 222.—Flask fitted with tube and water trap for passing steam into water; *S*, *S'* is a screen.

4. Cooling produced by evaporation.—Sprinkle a few drops of spirits of wine, or ether, on your hand. Notice that the liquid soon disappears, and its presence in the air can be detected by its odour. The rate at which the liquid evaporates is increased by waving the hand about. The hand feels cold.

5. Heat liberated when steam is condensed.—(*a*) Put equal quantities of cold water into two beakers of the same size. Observe the temperature. Boil water in a flask with a delivery tube (Fig. 222), and pass the steam into the cold water in one of the beakers. When the temperature of the water has been raised about ten degrees, take away the delivery tube, pull the cork out of the flask, and pour enough boiling water from it into the other beaker to raise the temperature by the same number of degrees. Find the weights of steam and water added to the cold water in the two beakers. It will be found that a small weight of steam, in condensing into water, produces the same heating effect as a much larger amount of water.

(*b*) Compare in the same way the heating effect of equal weights of steam and boiling water. To do this, pass steam into cold water and, by weighing, determine the amount condensed. Then add, to an equal amount of cold water, a quantity of hot water equal to the quantity of steam condensed.

Water and weather.—The character of the climate of a place depends profoundly upon the behaviour of water under different conditions of temperature. The importance of the high specific heat of water in this relation has been emphasised in Chapter XII, and it is now necessary to consider what changes in the state and density of water are brought about by variations of temperature, and what is the effect of such changes upon the weather.

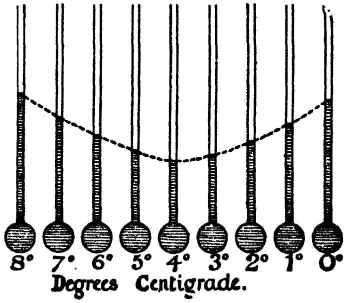


FIG. 223.—Changes in the volume of water between 8° C. and the freezing point.

Changes in volume and density as water is cooled.—If the volume of a body becomes greater whilst the quantity of matter in it remains the same, what is called the **density** of the body must become less and less. It is quite clear that if the same amount of matter occupies a larger space, it must be packed less closely into that space, and it is **the closeness with which matter is packed into a space** which is referred to by the term density. The general effect of a rise of temperature upon bodies is to cause them to expand, and therefore to decrease their density ; while a fall of temperature causes them to contract, and therefore increases their density. Water forms an interesting exception to this rule. When water is cooled gradually, the same mass of water becomes smaller and smaller in volume as it is cooled down to 4° C. (Fig. 223). We can express the same fact in another way, and say that its density becomes greater as it is cooled down to 4° C. From this temperature the volume of the water gets larger as we continue to cool it, and its density therefore becomes less. On the contrary, if we began with water at 0° C. and gradually warmed it, the density would increase steadily up to 4° C., and from that temperature upwards the density would diminish regularly.

Maximum density of water.—Because any mass of water has a smaller volume at 4° C. than at any other temperature, or, what is the same thing, has a greater density at this than at any other temperature, we speak of 4° C. as being the temperature at which water has its **maximum density.**

This may be summed up in the statement that **water at a temperature of 4° C. will expand whether it be heated or cooled.**

Results in nature of the peculiar expansion of water.—From a consideration of the expansion and contraction of water, it is easy to understand what happens when the water of a pond is cooled gradually on a frosty night. As the temperature of the water at the surface becomes lower and lower, the water there becomes smaller and consequently denser. It therefore sinks, and its place is taken by warmer water from below. The same cooling and sinking of the surface water continue until the temperature of the whole of the water is 4° C., at which temperature it has its maximum density, and consequently when the water at the bottom of the pond reaches this temperature it remains where it is. After the temperature of the water at the surface has reached 4° C., any further cooling causes it to expand and become lighter, and this result continues until 0° C.

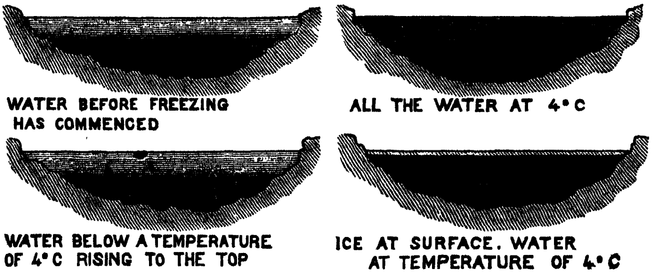

WATER BEFORE FREEZING HAS COMMENCED
ALL THE WATER AT 4° C
WATER BELOW A TEMPERATURE OF 4° C RISING TO THE TOP
ICE AT SURFACE. WATER AT TEMPERATURE OF 4° C

FIG. 224.—Stages in the freezing of a pond of water.

is reached and the water at the surface is changed into ice, which, being considerably lighter than water, remains on the surface. Ice is, moreover, a very bad conductor of heat, and consequently the temperature of the water below the ice gets cooler very slowly, and the thickness of the ice increases at but a small rate (Fig. 224).

This condition of things prevents several disastrous consequences which would of necessity follow if ice were denser than water. If ice were denser than water, it would sink to the bottom of the pond at the moment it was formed, and as the frost continued, the ice would spread throughout the water. Not only would this result in the destruction of many water animals in the pond, but it is probable that the heat of summer would be insufficient to melt it completely.

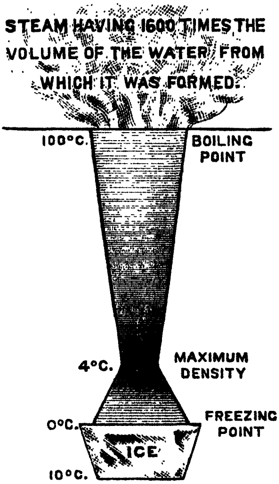

STEAM HAVING 1600 TIMES THE VOLUME OF THE WATER FROM WHICH IT WAS FORMED.
100°C.
BOILING POINT
4°C.
MAXIMUM DENSITY
0°C.
FREEZING POINT
ICE
10°C.

FIG. 224A.—Effect of prolonged heat upon chilled ice. The diagram shows how the chilled ice expands as it is warmed, and contracts when it melts. The water contracts at first, and then expands until it boils. (Changes in volume are here exaggerated.)

Expansion of water as it freezes.—When water is cooled to 0° C. and changes into ice, the ice which is formed takes up more room than the water does (Fig. 224A). In forming ice, the water expands; in fact, every 9 cubic inches of water produces about 10 cubic inches of ice. It is because of this expansion of water that people living in cold countries often have their water-pipes bursting during frosty nights. The bursting of the pipe of course takes place with the expansion that accompanies the formation of ice when freezing occurs, but is only discovered when the ice melts to water, *i.e.* when the thaw takes place. This has given rise to a belief among some people that thawing causes the pipes to burst, but that is obviously quite wrong.

Change of state.—When a solid body is melted by heat and is turned thereby into a liquid, or a liquid is changed into a vapour, or when the reverse changes take place, without any alteration in chemical composition, the body is said to undergo a change of state. Thus, if we heat ice it is first liquefied or becomes water ; and, on continued heating, it is vaporised or becomes steam.

Temperature of melting.—When a solid is heated, the first effect is usually an increase of size. But if the heating is continued long enough, when the solid reaches a certain temperature, which differs with different solids, melting begins. The solid changes into a liquid. The temperature at which the melting takes place is called the **melting point.**

In general, so long as any of the solid remains unmelted, the temperature does not rise above the melting point. When a Centigrade thermometer is placed in some pieces of clean ice, the thermometer records a temperature of 0° C. If some of the ice is put into a beaker, and a little water is poured in, the thermometer still records a temperature of 0° C. Even when the beaker, with the ice and water in it, is put over a laboratory burner and heated gently, the thermometer still reads 0° C., so long as there is any ice unmelted. It is evident, then, that the temperature of melting ice is always the same, and remains the same so long as there is any ice unmelted.

Latent heat.—These experiments are of the greatest importance, and should be understood clearly. It is certain that when a mixture of ice and water is heated over a laboratory burner heat is being given to the mixture continually. Yet the temperature as recorded by the thermometer does not rise. The question arises, what becomes of this heat, as it has no effect upon the temperature of the mixture? The ice is melted gradually and, if the heating is continued long enough, is all changed into water. As soon as this has happened, every further addition of heat raises the temperature of the water. These considerations lead to the conclusion that the heat previously given to the mixture is all used up in bringing about the change of ice into water.

This amount of heat which is necessary to change a solid into a liquid is spoken of as *latent heat.*

Latent heat of water.—The amount of heat which is required to change the state of a gram of ice, converting it from the solid to the liquid condition without raising its temperature, would be sufficient to raise the temperature of a gram of water through 80° C., or would raise that of 80 grams of water through 1° C. Similarly, to melt 1 lb. of ice requires as much heat as is necessary to raise the temperature of a pound of water from 0° C. to 80° C., or as much heat as would raise the temperature of 80 lb. of water through one degree Centigrade. The fact is often expressed by saying that the latent heat of water—or **the latent heat of fusion of ice—is 80.**

Natural consequences of latent heat of water.—Just as it is necessary, before a pound of ice can be changed into a pound of water, to pour into it an amount of heat which would raise the temperature of a pound of water through 80° C., so before a pound of water can be changed into a pound of ice, precisely the same amount of heat must be taken from it. This is why it needs so many cold nights to cover a pond with ice, for not until every pound of water at the surface has had this large amount of heat taken from it can it change into ice. For just the same reason it requires a large amount of heat to melt completely the snow in the roads and the ice on the ponds, so that the snow and ice do not disappear as soon as a thaw has set in.

Convection.—The process by which water and other fluids are heated must be noticed here. The water nearest the source of heat is heated, expands, and in consequence becomes lighter ; it therefore rises through the general mass of the liquid; something must take its place, and the cold water at the top, being heavier, sinks and occupies the space of the water which rises. This water in its turn gets heated and rises, and more cold water from the surface sinks. This behaviour gives rise to upward currents of heated water and downward currents of cool water, until by-and-by the whole of the water is heated. Such currents are known as **convection currents,** and the process of heating in this manner is called **convection.**

Boiling.—Eventually the water as a whole becomes so hot that the bubbles of vapour which are formed near the source of heat are not condensed again in their upward passage through the liquid, and coming to the surface they escape as steam. The liquid is then said to *boil.* The temperature at which bubbles of this sort are formed throughout the mass of the liquid is quite definite (when the pressure of the atmosphere is the same), and is called the **boiling point.**

Effect of pressure on the boiling point.—A word or two must be said with respect to the reservation which has been made in the last paragraph, and also on p. 366, about the pressure of the air. The weight of the atmosphere is considerable. It presses upon the surface of every body with a force dependent upon the extent of the air above the body; this force will clearly be less at the top of a mountain, and greater at the bottom of a mine.

If we wish to boil a liquid, therefore, in circumstances where the pressure of the atmosphere is great, we shall have to heat the liquid more, before the bubbles of vapour can escape at the surface, than when the pressure is less. If we heat the liquid more, its temperature will get higher before boiling takes place, and consequently its boiling point will be higher when the pressure is greater. The boiling point of a liquid therefore depends upon the pressure of the atmosphere at the time and place of the experiment.

Heat disappears during vaporisation.—When a liquid is changed into vapour a certain amount of heat is used up. It does not matter whether the liquid evaporates quietly, or boils; every gram of it requires a certain amount of heat before it becomes converted into vapour. In boiling, this heat is supplied by the flame or fire, and in ordinary evaporation it is taken from the objects in contact with the liquid. The faster the evaporation, the more rapidly heat is absorbed in this way. When a liquid evaporates rapidly, the cooling produced is very noticeable. For instance, if a few drops of either spirits of wine, or ether, are sprinkled on the hand, the liquid soon disappears and the hand feels cold. The heat necessary for the evaporation of these liquids is taken from the hand, consequently the hand becomes cooler and cooler as the vapour is formed.

In tropical countries, where the land becomes *very hot* during the day, evaporation takes place so rapidly after sunset that the water is sometimes so much cooled as to freeze, by the extraction of the heat required to bring about the change from liquid to vapour. It is readily noticed that not only is the dust laid by watering the roads in summer, but the air is pleasantly cooled by the evaporation of the water.

Latent heat of steam.—When once water in an open vessel has begun to boil, its temperature gets no higher than the boiling point. So long as there is any water left, no matter how much it is heated, its temperature remains the same. All the heat is absorbed, or used up, in bringing about the change from the liquid state to that of vapour. It requires much more heat to convert one gram of water at a temperature of 100° C. into steam at the same temperature, than it does to change a gram of ice at 0° C. into a gram of water at 0° C. In fact, whereas the heat required to bring about the latter change would raise 80 grams of water through 1° C., the amount of heat necessary to vaporise 1 gram of water would suffice to raise the temperature of no fewer than 536 grams of water through 1° C. This is expressed by saying that the latent heat of steam—or **the latent heat of vaporisation of water—is 536.**

The exact amount of heat which becomes latent, when a liquid is converted into a vapour, is liberated when the vapour is once more condensed to form a liquid. It is for this reason that a scald from the steam of boiling water is worse than a scald from the boiling water itself, and that the air is warmed by the formation of rain in cold weather (p. 382).

34. WATER VAPOUR IN THE ATMOSPHERE

1. Presence of water vapour in the air.—(*a*) Weigh a dish containing some dry calcium chloride, and then expose it to the air for some hours. Notice that the substance soon becomes pasty, and after a time dissolves in the water it has absorbed from the air. Find the increase in weight.

(*b*) Expose a small beaker one-third full of oil of vitriol (*i.e.* strong sulphuric acid—*a most corrosive substance*) to the air for several days. Notice that the liquid increases in volume and weight. Why?

(*c*) Do you suppose there is much moisture in the air present in well-stoppered bottles of strong sulphuric acid or of calcium chloride? Why? What method is employed in your school for keeping the air dry inside balance cases?

2. Dew point.—Gradually cool some water in a tin can, a thin glass tumbler, or beaker, by adding powdered ammonium chloride or nitrate and stirring with a thermometer. Watch the outside of the vessel (avoiding breathing upon it), and as soon as it becomes dimmed with moisture (dew), notice the temperature of the contents of the vessel. This temperature is the *dew point* at the time and place of the experiment. What is the source of the dew? Fan the vessel vigorously; does the dew persist? Wipe the outside of the vessel dry, and put it quickly into a balance case in which there is provision for keeping the air dry. Is the dew point the same inside as outside the balance case?

Do you suppose dry air requires more, or less, cooling than moist air at the same temperature before it deposits any of its water vapour as dew?

Find out whether, at any given temperature, the *rate of evaporation* of water varies according to the amount of moisture already present in the air, and if so, how the rate is affected. (Place the same number of drops of water, from a burette, in similar watch-glasses, and notice how soon the water dries up when the watch-glasses are kept in places differing in dryness of air.)

3. Mason's hygrometer.—Take a reading with Mason's hygrometer (the wet and dry bulb thermometer, Fig. 225), just *outside* a balance case in which there is provision for drying the air. Which thermometer shows the lower temperature? Why is the wet bulb cooler than the other? What is the difference between their temperatures? Now put the apparatus *inside* the balance case. Is the temperature of the air the same inside the case as it is outside? Does the temperature of the wet bulb remain the same inside the case as outside? Is the difference between the temperatures of the dry and wet bulbs greater when the instrument is inside, or when it is outside, the case? Why? How could you find out, by using the wet and dry bulb thermometer, which of two rooms, at the same temperature, contained the drier atmosphere? How could you learn, without actually determining the dew point, whether the temperature of the air was near, or far from, the dew point?

4. Dew. (*Outdoor work.*)—(*a*) Is dew deposited more freely on calm or on windy, on clear or on cloudy, nights?

(*b*) Find the dew point in the open air towards evening. To what temperature will the ground require to be cooled in order that dew may be deposited on it? Leave out a minimum thermometer on the ground, and examine it next morning, as soon after sunrise as possible, to see if this temperature has actually been reached during the night. Has dew been formed ? On what objects have you observed dew to be deposited most and least freely respectively?

(*c*) Arrange stones, pieces of slate, and sheets of paper, on grass on a clear, still evening, and next morning examine them as soon after sunrise as possible ; observe whether dew is more abundant on their upper or on their lower surfaces. Similarly, experiment with inverted tumblers, earthenware jars, etc., some on grass and some on soil ; also invert similar vessels, side by side with the former, but on metal plates, slates, or tiles. Compare the results in the two cases, both on clear nights and on cloudy nights.

5. Hoar frost. (*Outdoor work.*)—Contrast the appearance of hoar frost with that of frozen dew. One covers the pavement with white particles ; the other with a glassy sheet of thin ice. Hoar frost is atmospheric moisture condensed *after* the temperature of the surface has fallen below 32° F. Does the formation of hoar frost without frozen dew indicate a relatively dry or a relatively moist atmosphere? Why? To what extent do your observations support this conclusion? Expose inverted tumblers, earthenware jars, etc., and try to discover whether hoar frost is ever formed on the under surfaces of objects on the ground.

Condensation of water vapour.—The water vapour in the air sometimes becomes visible, assuming one of different forms according to the circumstances bringing about the necessary condensation. Some of the commonest products of this condensation are *dew, hoar frost, fog, mist, clouds, rain, snow and hail.* Since all these phenomena are results of the conversion of the water vapour either into liquid or solid water, it will be desirable to refer briefly to the conditions which result in such condensation.

Evidently condensation and evaporation are exactly opposite processes. Since the absorption of heat is necessary for the conversion of a liquid into a gas, there will be a liberation of heat when the contrary change, from the gaseous to the liquid condition, is effected, or when the gas is condensed. Any process which results in the continued cooling of moist air will cause some water vapour to assume one of the states enumerated, and all the circumstances to which we shall have to refer are really methods of bringing about such a lowering of temperature.

Hygrometry.—Air always contains water vapour. The actual quantity it is able to hold depends upon the temperature of the atmosphere. Consequently there will be more present in summer than in winter, although, judging only by the feelings, one would say that the air was drier during summer. This sensation of dryness results from the fact that the air could take up more water vapour than there is in it, since it is at a higher temperature. The ratio, which the amount of water vapour actually present in the air has to the maximum quantity it could take up at that temperature, is called the *relative humidity* of the air at the time and place of the experiment. The relative humidity or degree of saturation of the air is ascertained by the use of an instrument called a **hygrometer.** There are many kinds of hygrometers.

By passing a known volume of air through a substance which has the power to remove all the moisture from it, such as calcium chloride or strong sulphuric acid, and noticing how much the dehydrating agent, as it is called, has increased in weight, the amount of moisture present can be found very accurately. The apparatus used is known as the **chemical hygrometer.**

A more usual plan, however, is to use a form of instrument known as **Mason's hygrometer.** It consists of two precisely similar thermometers, suitably attached to a wooden stand as in Fig. 225. Round the bulb of one of the thermometers is tied a piece of muslin to which cotton threads are attached and hang into water kept in a glass, supported as shown. The instrument depends for its use upon two facts. The first is that water is vaporised only at the expense of a certain amount of heat, and secondly, the quantity of water vapour which air can take up at any temperature depends upon the amount already contained by it. Water rises up the cotton threads by capillary attraction, and consequently keeps the muslin moist. The water on the muslin evaporates, getting the heat necessary for evaporation from the bulb of the thermometer which it surrounds. The thermometer is thus cooled and the column of mercury sinks. This process continues until the air round the bulb is saturated and evaporation ceases. Thus the wet bulb thermometer records a lower temperature than the one with a dry bulb. The drier the air at the commencement of the observation, the greater is the difference between the readings; this difference and the temperature being known, the amount of water vapour present may be found by consulting tables.

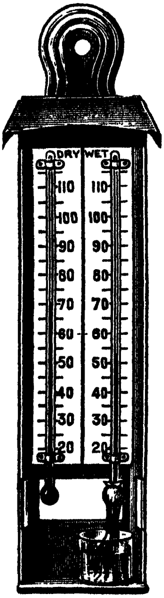


FIG. 225.—Mason's hygrometer.

Dew.—Dew differs from rain, snow and hail in being formed *upon* the surface of the earth. After sunset, the surface of the earth, which has been receiving heat throughout the day, begins to radiate this heat. Different parts of the earth possess differing powers of radiation. Those which during the day absorb heat to the greatest extent radiate it most abundantly after the sun has set, and consequently become cooled more quickly than those of smaller radiating power. Similarly, the air in contact with these bodies also becomes cooled and is then unable to hold as much water vapour as before, and the surplus is deposited in the form of **dew.** The temperature at which this deposition begins is called the **dew point** (Expt. 2, p. 405).

For an abundant formation of dew several conditions are necessary. First, radiation must go on freely, and this happens on *bright clear evenings* when there are no clouds to obstruct the radiation. The air which is being cooled by contact with the body from which free radiation is taking place must not be disturbed before the dew point is reached, or no dew will be thrown down, that is, the *evening must be still.* A breeze would constantly renew the air above the body being cooled by radiation, and thus prevent the dew point from being reached. The best radiating surfaces are those of leaves, whether of grass or other plants ; stones and similar things are also good radiators.

Side by side with this simple condition of things, another process is going on which augments the amount of dew formed. Throughout their life, plants continually give off water in the form of vapour, which is exhaled through the numerous apertures spread over their leaves, especially on the under surfaces. This process, known as *transpiration,* supplies a large amount of water vapour to the air. Dr. J. Aitken has shown that when the cooling spoken of above has gone on for some time, and the dew point has been reached, the transpired moisture, instead of diffusing into the atmosphere in the state of vapour, is condensed at the little aperture on the leaves as soon as it comes into contact with the cooled air. Thus, the dew is not all obtained directly from the atmosphere.

Other considerations in connection with formation of dew.— Colonel W. B. Badgeley made a number of experiments with a view of determining what part both plants and the earth itself take in the formation of dew, as well as of ascertaining whether the amount due to their agency, if any, varies at different times of the year. He arrived at the following conclusions :

1. The earth always exhales water vapour by night, and probably a greater quantity by day.

2. The quantity of water vapour given off by the earth is always considerable, and any variation in the quantity is mainly due to the season of the year.

3. The *greater part of the dew comes from the earth vapour.*
4. Plants exhale water vapour and (in general) do not exude liquid moisture.

This fourth conclusion is of particular interest, since it indicates that the dew formed on plants does not come out of them in the form of actual droplets, but of vapour which is afterwards condensed into liquid water.

These observations and experiments were extended by the Hon. Rollo Russell, who experimented with glass tumblers and pans, which he inverted over grass and bare earth and left out during the night. He invariably found that the interiors of these vessels became covered with a deposit of dew whenever the evenings were clear. With a view of eliminating every objection which could be urged against his conclusions, he inverted similar vessels on earthenware or metal plates placed upon the ground, and in these circumstances dew was never formed on their inside surfaces. In the first case the dew found covering the interior of the vessels probably represented the condensed vapour which had been exhaled from the earth or grass.

Russell showed also that the interior of glasses inverted over grassy turf was always more thickly covered with dew than in the case of those which were placed similarly over a turf which had been robbed of its grass. Plates suspended immediately over grass became more bedewed than similar plates suspended over bare earth, results which might have been anticipated from the greater radiating power of grass added to the amount of moisture transpired.

The deposition of dew is favoured, too, by a humid atmosphere, especially when it is calm. From what has been seen of the fundamental cause of the formation of dew it is clear that free radiation, which is more likely to occur in exposed situations, is most effective in the production of dew. Hence most dew is formed on good radiators, and *whatever diminishes the view of the sky diminishes the* quantity of dew.

Hoar frost—or as it is sometimes called, *white rime*, or simply **rime** —is deposited instead of dew on evenings when the radiation cools the overlying air to the temperature of freezing water before any deposition of moisture takes place. Hoar frost is *not* frozen dew. It does not first assume the liquid condition, but is precipitated at once in the solid form. In these circumstances the dew point is at, or below, the freezing point.

35. CLOUDS, RAIN, SNOW AND HAIL

1. Vapour and steam.—(*a*) Watch the steam issuing from the spout of a kettle or the mouth of a flask in which water is boiling. At what distance from the spout does the steam become visible? What is there between the spout and the visible steam? Put a cold object into this space for a moment and observe the drops of water condensed on it. Hold a red-hot poker in the same position until it cools, and describe the effect upon the steam.

(*b*) Observe the space above boiling water inside a glass flask ; is it clear or cloudy? Fan, or blow, some cool air into the flask. Explain why the space becomes cloudy for a moment.

(*c*) Leave a small saucer of water inside the receiver of an air pump until the air of the receiver is saturated with moisture. Then work the pump and observe that the air becomes cloudy.

2. Mist and fog.—(*a*) Try to frame definitions of mist and fog, to show in what respects they differ from each other and from clouds. How (i) by a change in your own position, and (ii) by a change in the position of the partly condensed vapour, could a cloud become mist, or mist become a cloud?

3. Cloud forms. (*Outdoor work.*)—Look for clouds similar in shape and appearance to those shown in Figs. 227 to 230, and in each case decide on the term which best describes the cloud—if necessary using such compound terms as cirro-cumulus, etc. Make a note, for future reference, of the direction in which the cloud was seen, of the direction in which the wind was blowing the smoke of near chimneys, of the direction in which the cloud appeared to be moving, of the kind of weather preceding and following your observation, and of the date and hour of observation.

4. Observation of halos.—Make a dated note of any halos (coloured arcs or circles around the sun or moon) you see ; describe this appearance and the character of the weather preceding and following each observation.

5. Rain.—(*a*) *The rain-gauge.*—Obtain a cylindrical vessel, *e.g.* a beaker, a pint mug or a jam-jar, and put in water to the depth of about a quarter of an inch. Given the means (*e.g.* a millimetre scale and a pair of dividers) of obtaining the internal diameter of the vessel, and also of measuring accurately the volume in cubic centimetres of the contained water, devise a method of finding the *depth* of the layer of water in the vessel, assuming the bottom to be flat and horizontal. The area of a circle $= (\text{radius})^2 \times \frac{22}{7}$.

(*b*) Examine a *rain-gauge* and its accompanying measuring-jar (Fig. 236). Its use is to find the *depth* of water falling as rain at any place during any given period (*e.g.* 24 hours) of time. Is it necessary to know the inside diameter of the top of the gauge? of the bottom? How is the measuring-jar graduated? Is the method of graduation a device for saving labour in calculation? If so, explain it. What is the use of the contained funnel? What precautions as to horizontality, nearness to other objects, etc., do you suppose are necessary in using the gauge? Make regular measurements of the rainfall; if you cannot obtain a standard gauge, make a gauge on the principles suggested above (Expt. *a*), and use it. Plot your results as in Fig. 237.

(*c*) *Rainbows.*—Is a rainbow visible before, during, or after a shower? Is it visible only when the sun is shining, or in " diffused " daylight also? In what direction, relative to the sun, must an observer generally look so as to see a rainbow best? What is the succession of colours (the " spectrum ") shown in the bow? Is the red end of the spectrum on the convex or the concave border of the rainbow? Make a special note of any double rainbows seen, or any rainbows of uncommon types?

6. Snow and hail. (*Outdoor work.*)—(*a*) *In places where snow falls.* Several times during the winter allow falling *snow* to fill a cylindrical jar (*e.g.* a large jam-jar); on each occasion note the temperature of the air. Melt the snow, and measure the volume of water produced; measure the internal height and the internal diameter of the jar, and calculate the volume. How many inches of snow are equivalent to one inch of rain? Is the result always the same? If not, is it affected by the temperature? Is snow more loosely or more closely compacted in colder weather? Observe and compare the sizes of snow flakes in very cold and in relatively mild weather. Catch falling snow on black velvet or paper, and examine the flakes with a lens; do you find the most perfectly formed crystals in the coldest weather, or not? On which side of neighbouring hills does the snow remain unmelted latest in the spring?

(*b*) Whenever there is a *hail* storm, collect hailstones of various sizes. Estimate the maximum size, and notice whether the large and the small stones differ in appearance. Melt some stones in cold water and, if possible, others in hot water and look carefully to see whether bubbles of imprisoned air escape from any. Crush other stones, both dry and in water, and observe their behaviour. Try to find out whether the stones are of solid ice, of a shell of ice surrounding a nucleus of snow, or hollow. Write a note of your results immediately, and add the date.

At what season of the year are hail storms most frequent in the part of India in which you live ?

Mists and fogs.—The general features of those forms of condensed moisture which are referred to under the names of mists and fogs are familiar to every one. **Mists** are most frequent near rivers or other water surfaces, and after the sun has set. They seem to be

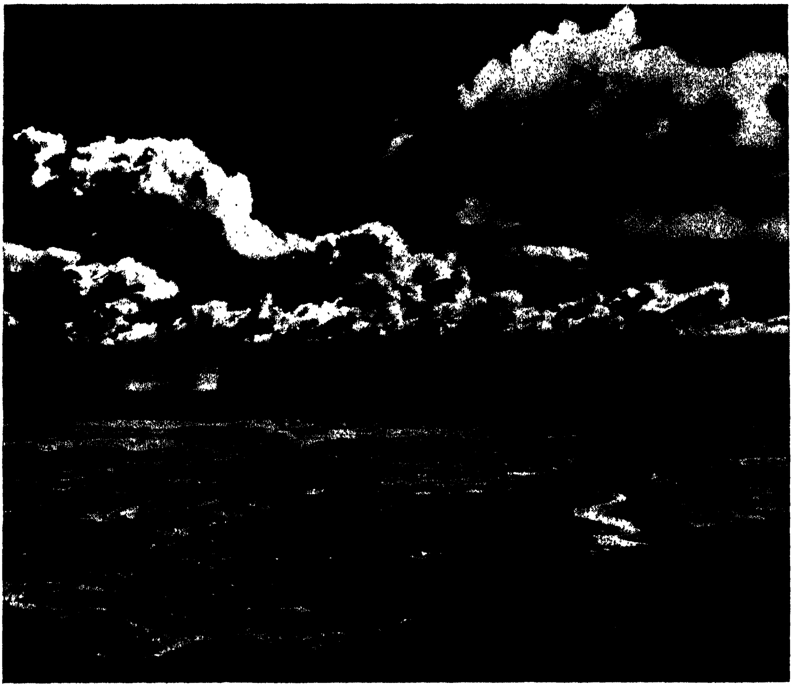


FIG. 226.—Cumulo-nimbus clouds and rain on the Siwalik range near Dehra Dun during the south-west monsoon. The photograph was taken late in September. In this area the monsoon arrives with mists which hide Dehra Dun from Mussoorie. The picture was taken from Mussoorie. (This information and photograph were supplied by Kinsey Bros., Mussoorie, and published with their kind permission.)

caused in this way: the air over the land cools more quickly than that over the water, partly because land radiates heat better than water does, and partly because it contains less heat than water at the same temperature (p. 377). The air over the water, being warmer, will rise, and the cold air will move towards the water to take its place. But the air over the water may thus be cooled below the dew point, and therefore be unable to hold as much water vapour as before, and the excess of moisture takes the form of a mist—that is, of minute particles of water suspended in the air in such abundance as to interfere with visibility. It is impossible to say when a mist becomes a fog. Most **fogs** are merely dense mists, for the condensation which forms a fog, like that forming a mist, takes place around small particles in the air, which act as nuclei for the minute water drops which make the air more or less opaque.

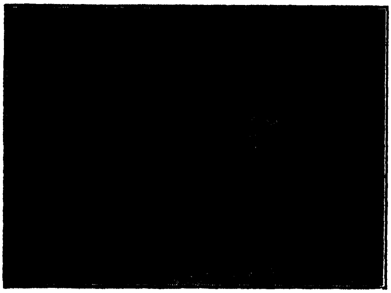


FIG. 227.—Cirrus cloud.

Some localities are rarely free from fog, since the permanent conditions are suited so exactly to its formation. Almost perpetual mists and fogs occur, for example, along the coast of Newfoundland, where the air above the warm water of the Gulf Stream, laden as it is with moisture, comes into contact with the cold Labrador current (Fig. 194). Just as a fog is caused by a lowering of the temperature of the air, so if the temperature again becomes raised by any means the obscurity will disappear. It is in this way that the mists are cleared away towards noon by the heat of the sun as it rises higher and higher in the heavens.

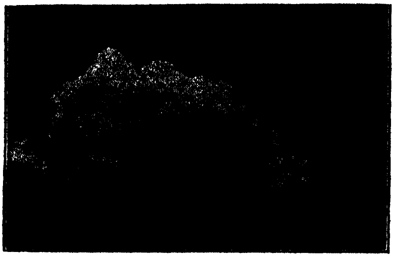


FIG. 228.—Cumulus cloud. (From a photograph by Dr. W. J. S. Lockyer.)

It is a common experience, in the ascent of a mountain, that mists are encountered as soon as the height attained becomes only a few hundred feet. Such mists are more properly to be regarded as low, drifting clouds.

Clouds.—Clouds are like mists in being composed of minute particles of water, but they originate quite differently. Whereas the condensation which forms mists is to be explained by the cooling of warm moist air either by blowing over a cold surface or by radiation of its heat into a clear sky, the cooling which forms clouds is due to the expansion which air necessarily undergoes whenever it rises in the atmosphere, because it is then subjected to a lower pressure (p. 435). In this way air not saturated with water vapour is cooled 1° C. for every 100 metres through which it rises in the atmosphere, and if the air rises far enough it is cooled to the temperature of saturation (the dew point). After this has been reached, any further ascent of the air causes condensation of some of the vapour it contains, and minute liquid particles of water are set free to form what Tyndall called "water dust", which becomes visible as a cloud.

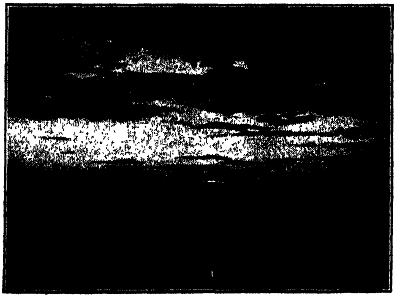


FIG. 229.—Stratus cloud. (From a photograph at Westgate-on-Sea, by Dr. W. J. S. Lockyer.)

The upward motion of air, which is **the necessary condition of the formation of cloud**—and therefore of the subsequent rain, snow or hail—may be caused in various ways. The upward direction which a range of mountains or hills imparts to a moist wind blowing against it accounts for the heavy rainfall of high land in general; while the unequal heating of the ground in hot weather—causing local upward currents of air—explains why hail falls most commonly in summer. There is naturally no very definite line of demarcation between one form of cloud and another, and several forms may be seen at the same time. Notwithstanding this, a number of clearly marked shapes can be recognised, and have been classified by meteorologists.

Classification of clouds.—The very existence of a cloud at any elevation is an indication that the atmosphere is there saturated, and the lower the cloud the more humid the atmosphere. A sky wholly clouded or overcast is cloudiness 10, while an unclouded sky is 0. The system of cloud classification, upon which the modern classification is based and still perhaps most widely known, was published by Luke Howard about a century ago. Three fundamental types (Figs. 227 to 229) were recognised, to which the names **cirrus**, **cumulus** and **stratus** were given. From these three primary forms Howard devised four intermediate forms, which he named cirro-cumulus, cirro-stratus, cumulo-stratus, and cumulo-cirro-stratus or **nimbus** (Fig. 230). **Stratus** is an unusual cloud in India, except in the cold weather in the damper parts of Bengal in the evening after sunset.

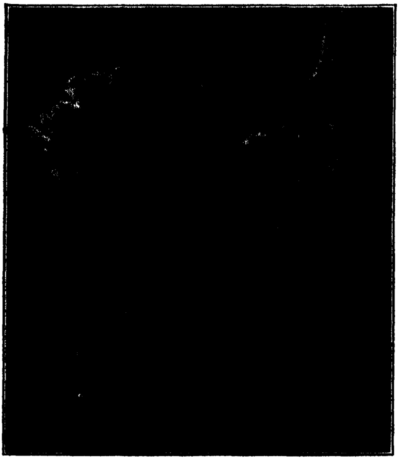


FIG. 230.—Nimbus cloud. Also see rain cloud in Fig. 226.
(From a photograph by Dr. W. J. S. Lockyer.)

This classification was elaborated by Poey *. Howard's modified nomenclature of clouds is still used by many meteorologists, but it is giving place to another, involving some of Poey's details, and is the standard classification adopted by an international meteorological congress, and therefore termed the international system. Ten different types of clouds are recognised in this system, and are numbered 1 to 10 from the highest form (cirrus) to the lowest (stratus).

In India a Classification of Clouds into Families and Genera is favoured. In the " Cloud Atlas " (2nd and revised edition, 1937) as below :

Cloud symbol	Name	Elevation and description
C	Cirrus	Usually appears at a great elevation, never lower than 6 miles up or above the Troposphere. It consists of minute snow brushes.
Cs	Cirro-stratus	Also a lofty cloud but denser and more sheet-like than Cirrus. It also consists of snow crystals and is sometimes thick enough to dim the sun's disc. It exhibits the phenomena of lunar and solar halos.
Ck	Cirro-cumulus	Also a lofty cloud, which forms by the breaking up of Pallio-cirrus. One form is the " Mackerel sky ", which are cloud tufts in ripple-like layers often seen after rain.
P	Pallium	Consists of Pallio-cirrus and Pallio-cumulus. The rain cloud.
Pc	Pallio-cirrus	A thick, lofty sheet cloud obscuring the sky and forming the upper layer of the Pallium or rain cloud. It is formed by the sinking and thickening of Cirro-stratus.
Pk	Pallio-cumulus	Thick mantle of cloud which makes the lower layer of Pallium or rain cloud. It is formed by the rapid increase and coalescence of cumulus. It extends higher than Cumulus.
K	Cumulus	One of the most familiar and typical cloud forms and is characteristic of the lower atmosphere. In Bengal, after a fine morning, nothing is more common than the clouds with rounded tops and flat bases—all about the same level. These are Cumulus and mark the summits of ascending air columns which reach saturation.
Fk	Fracto-cumulus	Broken masses of Pallio-cumulus. It belongs to the lower atmosphere and is commonly termed " Scud ".

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* After H. F. Blanford, "The Indian Meteorologist's Vade-mecum", 1877.

of the India Meteorological Department it is stated "All clouds may be classified into four rather distinct *families*, each of which may further be classified into two or more *genera*. The families, their most common heights * above the earth, and their genera are given below:

Family A : High Clouds

Mean upper level: 12 Km.
Mean lower level: 7 Km.

1. Genus *Cirrus* (Ci).
2. Genus *Cirrostratus* (Cs).
3. Genus *Cirrocumulus* (Cc).

Family B : Medium Clouds

Mean upper level: 7 Km.
Mean lower level: 3 Km.

4. Genus *Altocumulus* (Ac).
5. Genus *Altostratus* (As).

Family C : Low Clouds

Mean upper level: 4 Km.
Mean lower level: close to the ground.

6. Genus *Stratocumulus* (Sc).
7. Genus *Stratus* (St).
8. Genus *Nimbostratus* (Ns).

Family D : Clouds with Vertical Development

Mean upper level: Variable; may go up to 10-12 Km. in Cumulonimbus.
Mean lower level: 0.5 Km.

9. Genus *Cumulus* (Cu).
10. Genus *Cumulonimbus* (Cb).

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* The heights given are for tropical latitudes and are applicable generally to level country. In mountainous regions, the heights above the ground would be generally lower than those indicated, the low clouds often actually covering the mountain top.

The various genera are described as follows :

High.

1. CIRRUS (Ci). (30,000 to 40,000 feet.) Detached clouds of delicate and fibrous appearance, without shading, generally white in colour, often of a silky feathery appearance.
2. CIRROSTRATUS (Cs). (23,000 to 33,000 feet.) Thin sheets or veils of whitish cloud which do not blur the outlines of the sun or moon, but often give rise to haloes.
3. CIRROCUMULUS (Cc). (23,000 to 33,000 feet.) Layers, patches or bands consisting of small white flakes or very small globular masses of semi-transparent clouds, without shadows and brilliantly white when lighted up by the sun. The cloudlets are generally arranged in groups, or lines, or form ripples resembling those of the sand of the sea-shore.

Medium.

4. ALTOCUMULUS (Ac). (13,000 to 20,000 feet.) A layer or patches composed of laminae or rather flattened globular masses, the smallest elements of the regularly arranged layer being fairly small and thin, with or without shading.
5. ALTOSTRATUS (As). (10,000 to 20,000 feet.) Striated or fibrous veil, more or less grey or bluish in colour. The sun and moon shows through it as though through ground glass, but without halo phenomena.

Low.

6. STRATOCUMULUS (Sc). (3,000 to 13,000 feet.) A layer or patches composed of laminae or globular masses ; the smallest of the regularly arranged elements are fairly large ; they are soft and grey, with darker parts.
7. STRATUS (St). (Ground to 2,500 feet.) A uniform layer of low cloud resembling fog but not resting on the ground. Stratus is often a local cloud, and, when it breaks up, the blue sky is seen.
8. NIMBOSTRATUS (Ns). (600 to 10,000 feet.) (Name substituted for the old name *Nimbus*.) A low structureless and nearly uniform layer of dark-grey colour, feebly illuminated, seemingly from inside. Precipitation is in the form of continuous rain or snow which may sometimes not reach the ground.The very low and often ragged clouds of this class are called *Fractostratus* (Fs), the " scud " of sailors.

9. CUMULUS (Cu). Thick clouds with vertical development, whose upper surfaces (which may be up to 3 km. above the cloud base) are dome-shaped and exhibit protuberances, while the bases are generally horizontal. When these clouds become ragged and thin and fragments can be seen floating away from them, the clouds should be described as *Fractocumulus* (Fc).

(Base: 3,000 to 10,000 feet.)

10. CUMULONIMBUS (Cb). (Thunder cloud or shower-cloud.) Heavy masses of cloud with great vertical development (up to 7 km. above cloud base) whose cumuliform summits rise in the form of mountains or towers which, later, often develop a fibrous and flattened structure resembling anvils. (See cloud above rain in Fig. 226.)

(Base: 1,500 to 8,000 feet.)

LINE-SQUALL CLOUD. A mass of turbulent nimbostratus or cumulonimbus formed at or near the boundary surface between two masses of air of different temperature, humidity and direction of motion.

As different clouds usually occur at different altitudes, it is easy to understand that they may give **indications of forthcoming weather.** An old proverb says, " The higher the cloud, the finer the weather ", and this is probably true in many cases.*

A rule which applies to one part of the world may not, however, be accurate for another; nevertheless, when used in connection with observations of temperature and pressure, or with a weather chart, cloud forms are of real service in weather forecasting. But, as in all departments of science, little satisfactory progress will be made unless the observer's work is systematic and orderly. It is not enough to admire the ceaseless succession of sky patterns which have been mentioned. Each observation should be at the time recorded with the notes and sketches necessary to make it intelligible when referred to at some future time. If this is conscientiously done for a few weeks, the student who makes such a cloud record will be surprised to find order presenting itself out of diversity, and regularity where only confusion seemed at first to prevail.

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* Of cumulus clouds, it is said:

" If woolly fleeces spread the heavenly way,
Be sure no rain disturbs the summer day ";

and of the cumulo-nimbus (the " shower cloud "):

" A round topped cloud, with flattened base,
Carries rainfall in its face."

Rain.—The particles constituting a cloud, that is, the water dust already spoken of, continually grow, in cooling and saturated air, and form larger drops. When drops reach a certain size the air can no longer support them in consequence of their increased weight, their surfaces not having increased in the same proportion,* and

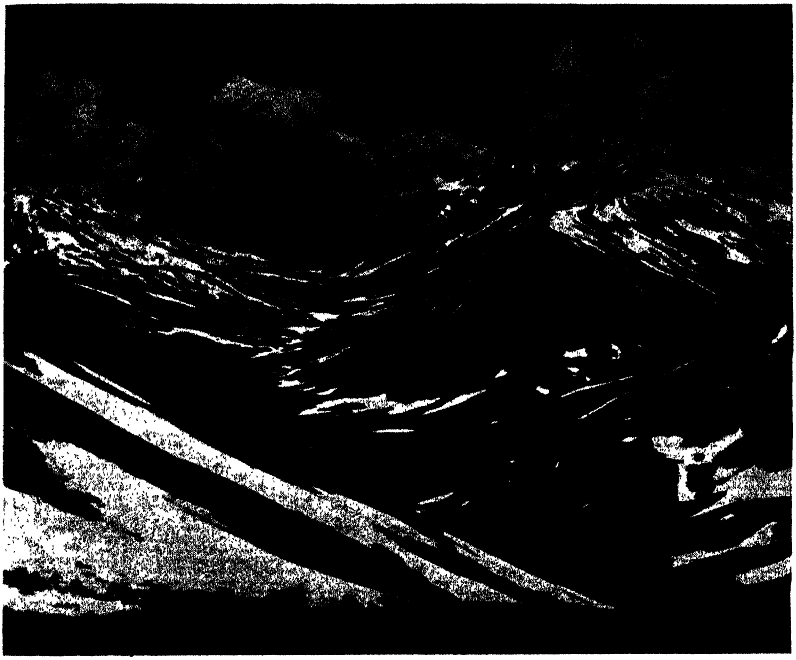

FIG. 231.—U-shaped valley and soft-featured hills, formerly covered by ice. View from San Sangri La, near Burzil, Kashmir. Remains of snow not yet melted (July). Note exceptional height (12,000 feet) of cumulus clouds. (With the permission of the Director, Geological Survey of India. Photo by J. B. Auden.)

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* The weight of a sphere is proportional to its *volume*, which is $\frac{4}{3}\pi r^3$. The *surface* of a sphere is $4\pi r^2$.

they fall, since they oppose less relative resistance to the air. They do not always reach the surface of the earth, however, for in their downward course it may happen that they have to traverse a layer of dry, unsaturated air, when the drops may become wholly evaporated again. In their passage through very moist air, then, raindrops continually get larger, whereas in falling through dry air they become smaller until they may even eventually disappear.

The formation of rain from the fine particles of " water dust " is controlled by the resistance which the air opposes to the drops of water falling through it. Owing to this friction, very small drops fall extremely slowly, even in still air, and are wafted to greater heights by a very slight upward current. Drops as small as $\frac{1}{1250}$ of an inch in diameter remain stationary because they are borne up and prevented from falling by air rising at speeds which are quite common in rainclouds ; but drops three times this size (*i.e.* about $\frac{1}{400}$ of an inch in diameter) are heavy enough to fall through the rising air of such clouds and to reach the ground as rain. The size of the raindrops is, in fact, decided by the speed with which the air beneath them is rising, the largest drops being naturally those which fall from the clouds in which the uprush of air is strongest—that is, from cumulus clouds. In general, the diameter of a raindrop does not exceed one-twelfth of an inch ; if it reaches one-fifth of an inch the drop flattens out in falling and breaks up into smaller drops, electricity separating at the same time. When this action takes place vigorously, it produces lightning and thunder.

Measurement of rainfall.—Of all the forms of condensed moisture which have now been described the most important, because it is the commonest and most abundant, is rain. The amount of rain which falls in a place is spoken of as the **rainfall** of that place. The student may have seen that the mean annual rainfall of Cherrapunji is four hundred inches. By such a statement is meant that, could all the rain which falls upon a particular area in that place be collected, none being lost, the amount which would accumulate during an average year would be sufficient to cover the area to a depth of four hundred inches.

For measuring the amount of rain which falls in a locality a simple instrument called the **rain-gauge** is used. There are many patterns of rain-gauges, but the object of them all is the same, *viz.* to collect all the rain falling on a known area, and store it in such a way that

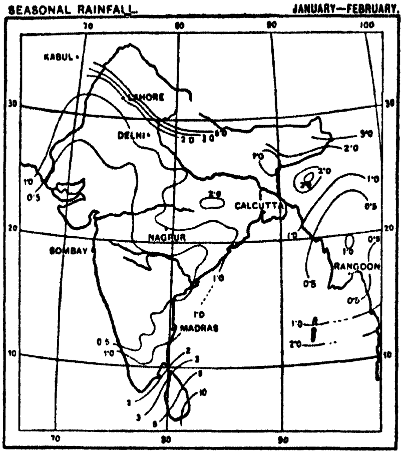

FIG. 232.

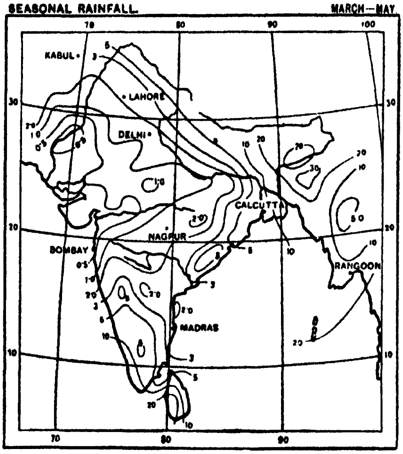

FIG. 233.

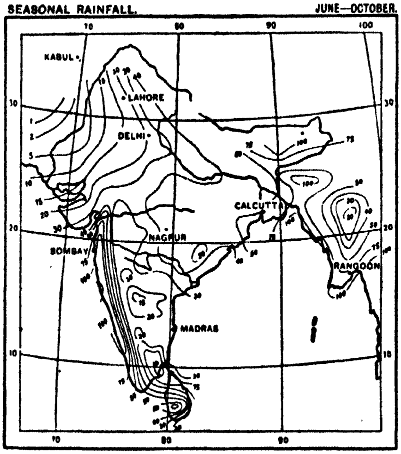

FIG. 234.

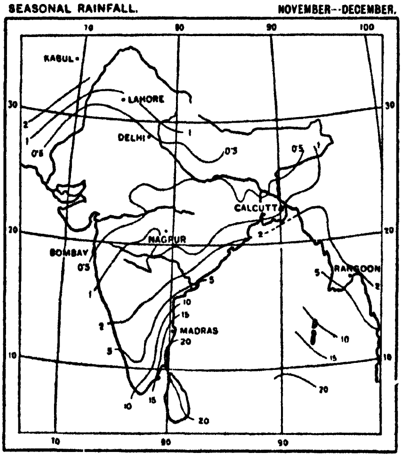

FIG. 235.

there is no loss by evaporation. A satisfactory form is that shown in Fig. 236, and its construction will be at once understood by reference to the diagram. It consists of a metal cylinder, in which a funnel fits accurately and directs the rain into a receiving vessel. The graduated jar, by the side of the gauge, is used to measure the amount of rain collected during the previous twenty-four hours from the time of setting the instrument. The upper edge of the cylinder has a sharp rim, so that the area receiving the rain collected is known with accuracy, and also the exact relation between it and that of the graduated vessel in which the water is measured. When, in addition, the amount of rain collected has been measured we have all the information necessary for calculating the rainfall of the place.

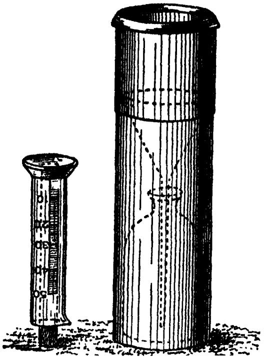

FIG. 236.—A rain gauge.

In speaking of the manner of recording the amount of rain, the expression *mean annual rainfall* is often used, and it will be desirable to make it clear what is thereby meant. One year may be much wetter than another, *e.g.* during 1861 a very large amount of rain, 905 inches, fell at Cherrapunji, whereas in the following year the rainfall was unusually small. Thus, by taking any one year we may get an entirely wrong estimate of the amount of rain which generally falls at a place, and to avoid this it is usual to add the amounts of rainfall for several successive

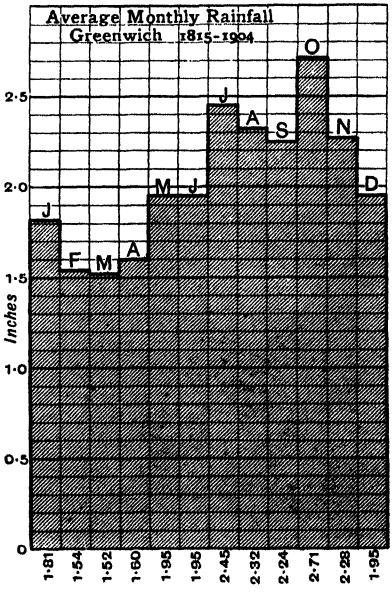

FIG. 237.—Average monthly rainfall at Greenwich from 1815 to 1904.

years together and divide by the number of years, thus obtaining the average for the years taken ; such a result is known as the mean annual rainfall of the place. Fig. 237 shows graphically the mean monthly rainfall at Greenwich from 1815 to 1904. The mean annual rainfall of the place is of course the sum of the separate monthly averages.

Snow.—Sometimes the temperature of a cloud is below the freezing point of water, and the water vapour present condenses directly in a solid form. If, in addition to this, the temperature of the air through which the descending solid particles pass is below the freezing point, we shall have a fall of solid particles in the form of **snow**. The falling particles unite continually to build up larger masses which we know as **snow-flakes** which, under favourable conditions, assume the most beautiful forms (Fig. 238). Ice crystallises in *hexagonal* forms, and snow-flakes are found on examination to be skeleton combinations of minute crystals of this kind, either as plates or as feathery stars. In this country the crystals are seen best when a fall of snow takes place in a still, quiet atmosphere, with the temperature at 0° C., or lower, to prevent a partial thaw from ruining their exquisite beauty. If the snow in its descent upon the earth becomes partly melted, and perhaps later partly frozen again, instead of snow-flakes reaching the surface we shall have a mixture of half-melted snow and rain, which is called **sleet.**

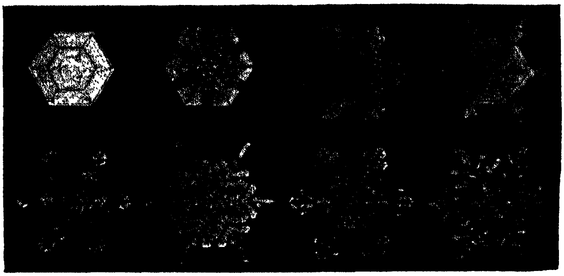

FIG. 238.—Photomicrographs of snow crystals.

Where the temperature of the atmosphere at the surface of the earth is never so low as the freezing point, as is the case throughout

India and Burma except in the Himalayas, the North-West Frontier and Baluchistan, snow cannot fall, for it will be melted before reaching the earth. Such a condition of things is found within the tropics, except on mountains upwards of 14,000 feet altitude, and extends to a distance of about 30° N.; while south of the equator, the limit is farther removed from the equator towards the Antarctic regions.

In high latitudes the average temperature is always below the freezing point, and snow exists on the ground all the year round. **That level, in any latitude, above which snow is found always, is called the snow-line.** This line touches the surface near the poles and attains its highest elevation in the tropics, where it never gets nearer than about 13,000 feet to the sea level (Fig. 126).

Hail.—In the peninsula of India hail falls more commonly in the cold weather or winter months than in the hot weather or rains. Hailstones take the form of pellets of ice, which may be hard or soft, and vary in size from that of a small pea to that of a small hen's-egg. In general, they originate near the top of cumulo-nimbus clouds (p. 413). In such clouds there is a rapid upward current of moist air.

The ascending air is cooled by expansion as it rises, until its dew point or temperature of saturation (p. 409) is reached, when cloud begins to form by the condensation of water vapour to form drops of liquid water (p. 415). Still rising, the air continues to cool and its contained water vapour to condense, but more slowly after the dew point has been reached—because the latent heat of vaporisation (p. 405) is being liberated with the change of water vapour to liquid. At length, however, the expansion of the ascending moist air lowers its temperature to 0° C., at which the liquid drops would normally freeze and form crystals of ice. It is believed that in the circumstances—owing to the purity of the water formed—the drops remain liquid when cooled considerably below 0°C. Such water is said to be super-cooled. Presently the temperature is reduced so low by the continued expansion of the rising air that the vapour still present freezes *directly* to form crystals of ice, which grow into pellets of soft hail heavy enough to overcome the resistance of the ascending air. It is in the upper part of the cloud that this takes place.

In falling through the lower part of the cloud, the very cold pellets of soft hail encounter the drops of super-cooled water, which solidify on the surface of the pellets to form shells of hard ice. The ice increases in thickness and the hailstones in weight as the process is continued. The time taken in the fall of a hailstone to the ground must obviously depend on its size and weight, and on the velocity of the upward current of air; and the respective effects, which variations in these respects would have, seem to account satisfactorily for the varying proportions of hard and soft ice in hailstones.

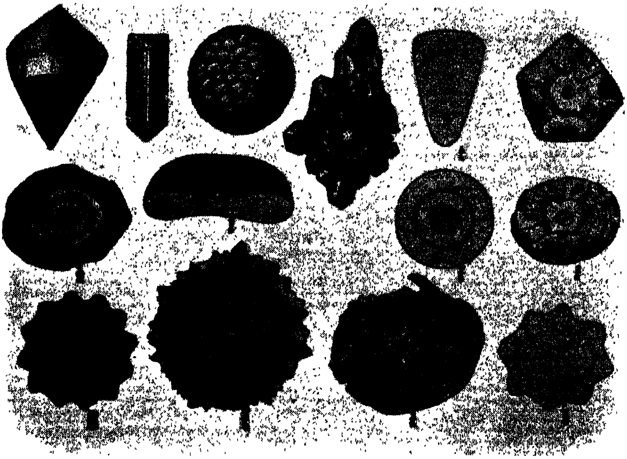

FIG. 239.—Hailstones, whole and in section.

Total precipitation.—The " total rainfall " of a place is considered to include all forms of precipitated moisture, whether rain, snow or hail, which can be measured.

The distribution of rainfall is so directly dependent on prevailing winds that it cannot be dealt with satisfactorily before the movements of the atmosphere have been studied. Rainfall distribution is therefore considered in Chapter XV.

EXERCISES ON CHAPTER XIII

1. How are fogs and mists formed, and why are they specially prevalent on the sea coast and at high elevations?

2. What is a cloud? Describe the appearance of the chief types of clouds. Illustrate your answer by sketches.

3. How is a cumulus cloud formed? Why are mountain peaks often surrounded by clouds when the rest of the sky is clear?

4. What is "an inch of rain"? Describe the construction and method of use of one form of instrument for measuring it.

5. What are the differences between rain, hail and snow? How do these differences arise?

6. Explain the formation of fog and mist. Why is fog or mist especially common (*a*) on mountain tops, (*b*) in marshy lands, (*c*) in London?

7. Taking the average annual rainfall of England, Scotland, Ireland, Wales and the United Kingdom as 32·5, 47, 42, 49, and 39 inches respectively, construct on squared paper, a diagram illustrating clearly the difference between them.

8. What causes rain? How is rain measured? The average monthly rainfall of a certain place from January to December is given in inches as 1·9, 1·5, 1·2, 1·5, 1·9, 2·3, 2·2, 2·3, 1·6, 2·3, 1·8, 2·1. Would you call this a *wet* place? Give reasons for your answer, comparing its rainfall with that of any other district you know. Convert the figures given into a diagram.

9. What causes tend to produce fog? Do you know any regions where fog abounds? Explain the causes in each case.

10. How is rainfall measured? What special precautions are necessary in the construction and use of a rain-gauge to ensure accuracy?

11. Name the different kinds of clouds, with some account of how the weather can be predicted from their appearance.

12. How do you account for it being so cold in the upper regions of the atmosphere when the sun is shining brightly?
What are the conditions which favour the formation of dew?

CHAPTER XIV

THE ATMOSPHERE AND ITS MOVEMENTS

36. THE PRESSURE OF THE ATMOSPHERE

1. The weight of air.—Fit a one-holed indiarubber stopper into a fairly large glass flask, and fit into the stopper a short tube with a stopcock upon it. Put a little water in the flask, open the stopcock, and boil the water. After boiling for a short time turn off the tap, and place the flask on one side to cool. When the flask is cool, weigh it, or counterpoise it. Then open the stopcock; air will be heard to rush into the flask, and as it does so the balance will show an increase of weight.

2. The pressure of the atmosphere.—Procure a thin tin can having a neck, into which fits an indiarubber stopper. Take out the stopper and boil a little water in the can. After the water has been boiling for some time, so that the can be practically filled with steam, remove the can from the flame, and quickly put in the stopper as tightly as you can. After a few minutes the can will collapse inward. Why? Why did the air rush into the flask in Expt. 1 above, when the stopcock was opened?

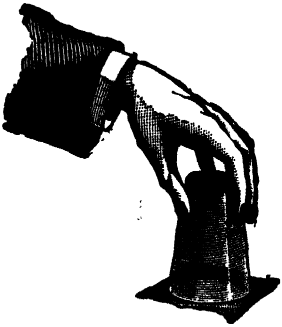

FIG. 240.—Experiment illustrating the pressure of the atmosphere.

3. The principle of the mercurial barometer.—(*a*) Take a tumbler or cylinder with ground edges and completely fill it with water. Place a piece of stout writing paper across the top and invert the vessel. If the air has been excluded carefully from the cylinder the water does not run out (Fig. 240). Think what keeps the paper in its place.

(*b*) Procure a thick glass tube about 36 inches long and closed at one end. Fill the tube with mercury, place your thumb over the open end, invert the tube, place the open end in a cup of mercury and take away your thumb. A column of mercury will be supported in the tube. What keeps it in position? Measure the difference in height between the top of the mercury column and the level of the mercury in the cup.

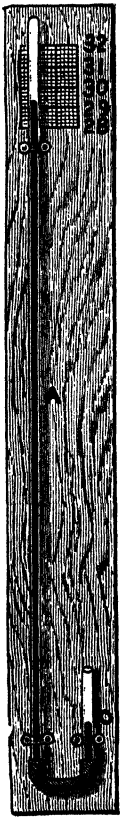

FIG. 241.—To explain the principle of the barometer.

(*c*) Fit a short piece of indiarubber tubing on the open end of a tube similar to that used in the last experiment (*b*). Tie the free end of the tubing to a piece of glass tube about six inches long open at both ends. Rest the barometer tube with its closed end downwards and pour mercury into it (being careful to remove all air bubbles) until the liquid reaches the short tube. Then fix the arrangement upright as in Fig. 241. What is the difference in height of the tops of the mercury columns in the two limbs? Empty the apparatus; then measure out this depth of mercury in the long tube, and weigh the mercury. Measure also the inside diameter of the tube; the area of the cross-section of the mercury column $= \text{radius}^2 \times 3\frac{1}{7}$. What would be the weight of the mercury column, supported by the pressure of the atmosphere, in a tube of 1 square inch cross-section? What is the pressure of the air, measured in pounds, per square inch?

4. Variation of barometric pressure.—Read the height of the barometer daily at the same hour for a month or longer, and keep a record of the heights and of the state of the weather (see Expt. 3, p. 443). Does the weather change before, with, or after the barometer?

5. Finding heights by means of a barometer.—Would you expect a barometer reading taken at the top of a mountain to be higher or lower than one taken at the foot at the same time? Why? The following approximate heights and barometer readings are said* to correspond when the barometer reading at sea level is 29·921 inches † and the temperature of the intermediate air is 32° F. :

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* Sir Charles Close's "Text Book of Topographical and Geographical Surveying" (H.M.S.O.).

† When the barometer stands at 29·905 in London and the thermometer is at the freezing point the equivalent reading in Calcutta would be 29·924 inches.

Boiling point of water	Barometer reading (inches)	Height (feet)	Boiling point of water	Barometer reading (inches)	Height (feet)
°F.			°F.		
212	29·921	—	203	24·952	4741
211	29·329	522	202	24·447	5278
210	28·746	1046	201	23·950	5815
209	28·174	1571	200	23·461	6354
208	27·613	2097	199	22·980	6895
207	27·062	2624	198	22·507	7439
206	26·521	3151	197	22·042	7984
205	25·989	3680	196	21·584	8533
204	25·466	4210	195	21·133	9084

Calculate in several instances the difference in altitude corresponding to a difference of 1 inch barometer reading. Is the proportion approximately constant? If not, does it increase or decrease regularly with the altitude? Do you consider the rule for moderate elevations, " 900 *feet altitude per inch of barometer height* ", a satisfactory one?

Test by the same table Clerk Maxwell's rule : * " *For rough purposes the differences of the logarithms of the heights of the barometer multiplied by* 10,000 *gives the differences of the heights in fathoms of six feet.*"

Assuming that the mean annual barometric pressure at the summit of Parasnath in Bihar is 25·0 inches ; at Fort-William, Calcutta (sea level), it is 29·85. Find the approximate height of the mountain, given

$$\log 29{\cdot}85 = 1{\cdot}47, \quad \log 25{\cdot}00 = 1{\cdot}40.$$

A barometer at the top of a mountain known to be 4256 feet high read 25·51 in. and at the bottom 29·81 in. The temperature at the top was 50·5° F. and at the bottom 63° F. Applying Clerk Maxwell's rule :

$$\begin{array}{l} \log 29{\cdot}81 = 1{\cdot}4743 \\ \log 25{\cdot}55 = 1{\cdot}4074 \\ \hline \end{array}$$

$$\therefore \text{ Height } = 0{\cdot}0669 \times 10{,}000 \times 6 = 4014 \text{ feet.}$$

How do you account for the discrepancy? Why ought such barometer readings to be corrected for temperature?

6. Aneroid barometer.—Examine a pocket aneroid (Fig. 35), and notice the scale of feet accompanying the barometer scale. Make as many height determinations with it as possible, and compare them with the results obtained by Clerk Maxwell's rule, neglecting temperature.

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* " Theory of Heat " (Longmans, 3s. 6d.).

The atmosphere.—Surrounding the earth in every latitude, over land and sea, is a gaseous envelope which is spoken of as the air or the atmosphere. Its presence when at rest is unperceived, though when moving it becomes apparent, since it imparts its motion to leaves and other bodies free to move.

Its existence may be demonstrated equally well in various other familiar ways. If a so-called " empty " bottle is inverted carefully in water, the water does not go in, because the bottle is already full of air. If the bottle is tilted, the air escapes as bubbles, and water takes its place inside the bottle. A person moving quickly across a room with a large sheet of paper or cardboard in his hands feels little or no resistance when the cardboard is held " edge on ", but finds his motion impeded when he holds it " broad-side on ".

Weight of the air.—Expt. 1 in this section affords an easy proof that air has weight. If the air is removed completely from a flask by means of an air-pump, the difference in the weighings, before and after, will provide the exact weight of a given volume of air. Thus, if the vessel has a capacity of a cubic foot, the difference of weight will be found to be nearly an ounce and a quarter.

It may be added that at sea level if when the air is perfectly still it causes the barometric column to stand at 30 inches (at 32° F.), then each square inch of the vertical column of atmosphere has a weight of 14·735 lb. (avoirdupois). The weight of one cubic foot of dry air under a barometric pressure of 30 inches at 32° F. is 565 grains. From these data it follows that if the atmosphere were of uniform density and at 32° F. its height would be 26,288 feet. This is called the height of the *homogeneous atmosphere* and is usually designated by **H** and taken roughly as 26,250 feet.

Pressure of the atmosphere.—It is a property of all gases and liquids that they communicate pressure in all directions. If air did not possess this property, pneumatic tires would have no advantage over solid tires, and numberless other useful and familiar devices of everyday life would be impossible. It is a consequence of this circumstance, too, that we are able to move about quite freely. Our bodies are subjected to an enormous pressure due to the whole weight of the atmosphere above us, and yet we are quite ignorant of it, at all events in ordinary circumstances. Why is this? The lungs which fill up a large part of our chest capacity are inflated with air. The inside air is under just the same pressure as that outside, and consequently there is an exact compensation, and we are not crushed.

The result of atmospheric pressure on a vessel having practically no compensating inside pressure is well shown in Expt. 2, Sect. **36**. The explanation of the effect produced in this experiment is that as the can cools, nearly all the steam inside is condensed into water, and so occupies a much smaller volume. The pressure which this steam exerts on the inside of the can is thus removed, while the pressure of the air on the outside remains practically the same, the result being that the can is crushed. At the sea level, under ordinary conditions, the pressure of the air is about 15 lb. on every square inch.

Another familiar illustration of the pressure of the air in all directions is found in a boy's leathern sucker. The difficulty of removing the sucker by a pull at right angles to the surface on which it has been pressed, is found to be the same whether the surface is horizontal, vertical, or oblique, facing upwards, or facing downwards. It is the pressure of the air which forces water into a syringe or squirt when the open end is placed in water and the piston is pulled up. It is the upward pressure of the air which balances the weight of the water filling a tumbler, which has been covered by a sheet of paper and then inverted (Fig. 240).

Principle of the mercurial barometer.—It has been seen that the air has weight, and that it exerts great pressure on the earth's surface; we have now to learn how this pressure is measured. In Expts. 3, *b* and *c*, p. 430 (Fig. 241), the mercury in the long tube will be seen to fall so as to leave a space of a few inches between it and the closed end. The difference in height between the top of the mercury column in the closed tube and that in the open tube will be found to be about thirty inches.

On reference to Fig. 241, it is clear that there is a column of mercury supported by some means which is not at first apparent, or else the mercury would sink to the same level in the long and the short tube, for we know that liquids tend to find their own level. If a hole were made in the closed end of the tube this would happen immediately. The column of mercury is kept in its position by the weight of the atmosphere pressing upon the surface of the mercury in the short open tube. The weight of the column of mercury and the weight of a column of the atmosphere with the same sectional area is exactly the same ; both columns are measured from the level of the mercury in the short limb of the barometer shown in Fig. 241, the mercury column to its upper limit in the long tube, the air column to its upper limit, which is a great distance from the surface of the earth, and probably very indefinite. If for any reason the weight of the atmosphere becomes greater, the mercury will be pushed higher to preserve the balance ; if it should become less, then similarly the amount of mercury which can be supported will be less, and so the height of the column of mercury is diminished.

The student will now understand why it is necessary to remove all the air bubbles in Expt. 3, *c*, p. 430. If this were not done, when the tube was inverted the enclosed air would rise through the mercury and take up a position in the top of the tube above the mercury. The reading would not then be thirty inches, for instead of measuring the whole pressure of the atmosphere, what we should really be measuring would be the difference between the pressure of the whole atmosphere and that of the air enclosed in the tube.

An arrangement like that described constitutes a **barometer,** which we can define as **an instrument for measuring the pressure exerted by the atmosphere.**

The height of the mercury column, which is sustained by the pressure of the air, is independent of the width of the barometer tube.

If the tube had an area of exactly one square inch, there would be thirty cubic inches of mercury in a column thirty inches long ; and since a cubic inch of mercury weighs about half a pound, the whole column would weigh about fifteen pounds. This column balances a column of air of the same area, so that we find that the weight of the column of air upon an area of one square inch is about fifteen pounds when the barometer stands at thirty inches.

Barometers as weather glasses.—The only direct measurement we can make with the barometer is that of the weight of the atmosphere. Since, however, this weight is influenced by a variety of circumstances which affect the weather, these variations of the atmosphere's weight can supply information respecting the probable weather conditions. If the atmosphere is warm and laden with moisture, it is lighter bulk for bulk than cold dry air would be. The prevalent south-west winds which influence the climate of Great Britain greatly affect also the upper regions of the atmosphere, warming them and saturating them with moisture, before we become aware, by the weather changes they produce, that they have arrived on the surface. But the whole extent of the atmosphere influences the height of the barometer, and consequently the changes brought about high up in the air, though they cause no change in the weather at the moment, do produce a difference in the weight of the atmosphere, lightening it, and causing the barometer to sink. Soon after come the corresponding weather changes, which are later results of the cause which brought about the change in the barometer reading. The barometer thus indicates what the weather is likely to be.

Why mercury is used for barometers.—The use of mercury for barometers is a matter of convenience. Since the column of mercury which the atmosphere is able to support is 30 inches high, it is clear that, as water, *e.g.*, is 13·6 times as light as mercury, the column of water which could be supported would be 30 × 13·6 = 408 inches = 34 feet, which would not be a convenient length for a barometer. The length of the column of glycerin which can be similarly supported is 27 feet. But in the case of lighter liquids like these, any small variation in the weight of the atmosphere is accompanied by a much greater alteration in the level of the column of liquid, and in consequence it is possible to measure such variations with much greater accuracy. For this reason barometers are sometimes made of glycerin.

Pressure of the atmosphere at different altitudes.—The atmosphere being a material substance, the longer the column of it which is above the barometer, the greater will be the weight of that column, and the greater the pressure it will exert upon the mercury in the barometer. Hence, as we ascend through the atmosphere with a barometer, we reduce the amount of air above which is pressing down upon it, and in consequence the column of mercury the air is able to support will be less and less as we ascend. On the contrary, if we can descend from any position, *e.g.*, down the shaft of a mine, the mercury column will be pushed higher and higher as we gradually increase the length of the column of air above it.

Since the height of the column of mercury varies thus with the position of the barometer, it is clear that the variation in its readings supplies a means of ascertaining the height of the place of observation above the sea level, provided we know the rate at which the height of the barometer varies with an alteration in the altitude of the place. The application of this principle in map-making has been explained on page 44.

The rule which expresses **the relation between atmospheric pressure and altitude** is not a simple one. When the air intermediate between the two places of observation is at a temperature of 32° F., the barometer falls, on the average, **about one inch for an ascent of every 900 feet** between sea level and a height of 1500 feet. Above this height the additional elevation required to produce a fall of an inch in the barometer becomes increasingly greater. It is, in general, more satisfactory to apply **Clerk Maxwell's rule**: "For rough purposes, the differences of the logarithms of the heights of the barometer multiplied by 10,000 gives the difference of the heights in fathoms of 6 feet." If accurate results are necessary, this rule also requires to be modified when, as is nearly always the case, the temperature of the intervening air is other than 32° F.; for a variation of temperature naturally causes expansion or contraction of the parts of the barometer as well as of the air affecting it. From these considerations it is evident that if barometer readings are to be used with any confidence for forecasting the weather, the height of the place of observation and the temperature must both be allowed for. It is for this reason that, in the Daily Weather Reports issued by the Meteorological Office in London, the barometer readings have all been "reduced to 32° F. and mean sea level ('M.S.L.')".

A second method of finding approximate heights is by observing the temperature at which water boils. As was explained in Chapter XII (p. 366), the less the atmospheric pressure upon it, the lower is the temperature which suffices to boil water, and *vice versa.* When the temperature of the intervening air is 32° F., the boiling point of water decreases fairly regularly at the rate of 1° F. for each 525 feet, up to altitudes of 4000 feet. (See Table, p. 431.)

Variation in density of air.—The volume of a given amount of air becomes *greater* as its **temperature** is *increased*, and becomes less as its temperature is decreased. In other words, an increase of temperature results in a decrease in the density of the air, while a decrease of temperature results in an increase of its density.

Changes in volume, however brought about, cause corresponding changes in density. By doubling the pressure on a portion of air, its volume is halved; by trebling the pressure the volume is reduced to one-third, and so on. This relation was discovered by Boyle, and is known as **Boyle's Law.** It can be expressed by saying that *when the temperature remains the same, the volume of a gas varies inversely*

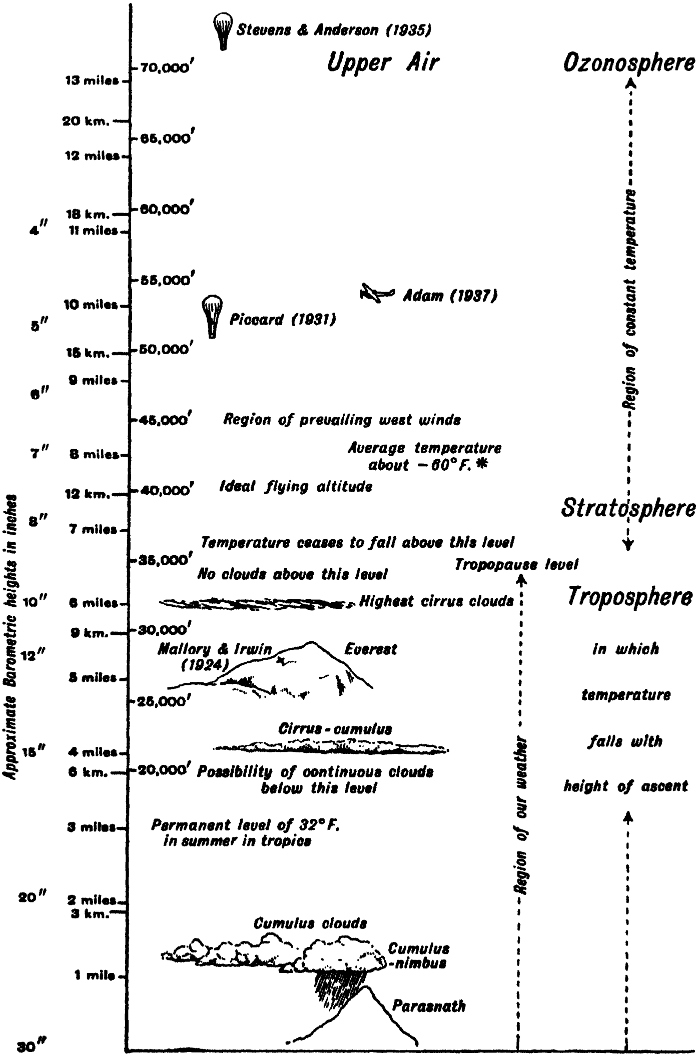

FIG. 242.—The atmosphere of our weather and the Upper Air. (The India Meteorological Department publishes a journal " Upper Air Data " (vol. viii., 1935, part 14), which deals with Balloon Sounding Data.)

* (See " Nature ", June 1, 1929, p. 834 : " Distribution of Temperature in the First 25 kilometres over the Earth ", by K. R. Ramanathan, Meteorological Department of India.)

as its pressure. Or, what is the same thing, *the temperature remaining the same, the product of the pressure into the volume is constant.*

But it is plain that if we increase the volume occupied by a given mass of a substance we decrease its **density**, or if we decrease its volume we increase its density. Thus, increase of density and increase of pressure are proportional to one another.

It is not difficult to apply these facts to the case of the atmosphere. The pressure of the atmosphere decreases as we ascend, and its density decreases at the same rate. Therefore the densest atmosphere will be that at the surface of the earth (if we leave out of consideration the air of mines and other cavities below the surface, where the air will be denser still). The air gets less dense or rarer as we rise above the surface of the earth, until eventually it becomes so rare that its existence is practically not discernible.

The pressure of the air varies in the same place.—That this is the case every one knows. If it were not so, the reading of the barometer would always be the same in any place, and the pressure being once recorded there would be no further use for the barometer there. We must now consider the reason of this variation. It follows naturally from the facts already stated that:

(1) An increase of temperature produces a diminution in the density of the atmosphere, and consequently a diminution of pressure, which is accompanied by a fall in the barometer.

(2) Water vapour is lighter than air in the proportion of 9 to 14·5. Consequently, if there is a large amount of water vapour present in the atmosphere at a place, the barometric pressure exerted will be less, since the air is thereby made lighter, bulk for bulk.

Thus the rule will be that, other circumstances remaining the same, an increase of temperature will be accompanied by a fall in the barometer; *i.e.* **where the thermometer is high the barometer is low.** Similarly, with the same reservation, an increase of the amount of water vapour in the air will cause a lower barometer reading. In order to map the pressure of the atmosphere in different parts of the world it is usual to draw lines through all those places which have the same barometer reading at any given time. Every morning, observers in the chief towns of this country, and sometimes ships in Indian waters, telegraph the height of their barometers to a central office in Alipore, Calcutta. These numbers—reduced to 32° F. and

M.S.L.—being placed against their respective towns on a map, it is quite easy to join those places where the pressure is the same at the particular time of observation. Lines so obtained are called " equal pressure lines ", or **isobars** (Figs. 256 and 257).

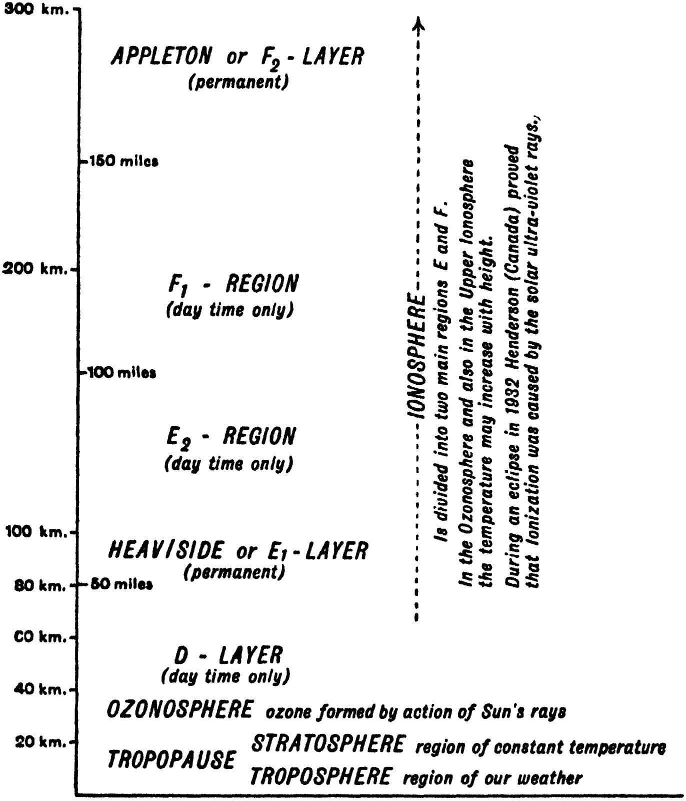
300 km.
APPLETON or F_2 - LAYER
(permanent)
150 miles
200 km.
F_1 - REGION
(day time only)
100 miles
E_2 - REGION
(day time only)
100 km.
HEAVISIDE or E_1 - LAYER
(permanent)
80 km.
50 miles
60 km.
D - LAYER
(day time only)
40 km.
OZONOSPHERE ozone formed by action of Sun's rays
20 km.
TROPOPAUSE
STRATOSPHERE region of constant temperature
TROPOSPHERE region of our weather
IONOSPHERE
Is divided into two main regions E and F.
In the Ozonosphere and also in the Upper Ionosphere the temperature may increase with height.
During an eclipse in 1932 Henderson (Canada) proved that Ionization was caused by the solar ultra-violet rays.

FIG. 243.—Atmospheric layers and their functions. The layers with the letters D, E_1 and F_2 reflect ether-waves used in radio-communication and broadcasting.

Height of the atmosphere.—Mount Everest is not quite five and a half miles high, and the height of the barometer at its summit is estimated at only about eleven inches instead of the thirty at the sea level; therefore, the pressure of the atmosphere is a little more than one-third, and the density is consequently also about one-third; or a cubic foot of air, instead of weighing one and a quarter ounces, would there weigh nine-twentieths of an ounce. The highest point ever reached by manned balloons,* up to 1937, is over 13¼ miles, at which height the barometer is less than three inches, and a cubic foot of air weighs barely one-sixth of an ounce. Nowadays, however, the atmosphere at greater heights than this, even up to 25 miles occasionally, is regularly explored by means of small balloons carrying self-registering barometers, thermometers and other instruments.

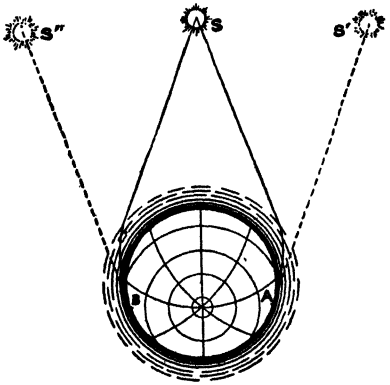

FIG. 244.—To show how atmospheric refraction causes the sun to be visible when below the horizons at *A* and *B*.

But there are ways by which the presence of the atmosphere can be demonstrated at even greater distances from the earth's surface. The sun always appears higher in the heavens than it really is, since its rays are bent on passing through the atmosphere. Thus, in Fig. 244, when the sun appears to an observer at *A* to be rising at *S′* it is really at *S* below the horizon. If it appears to be at *S″* and therefore setting, to an observer at *B*, it really has set at some previous moment. It is possible, from these considerations, which account for the phenomenon of **twilight** before sunrise and after sunset, to demonstrate the presence of air at a distance of forty-five miles from the earth's surface.

The phenomena of meteors or shooting stars also provide the astronomer a means of proving the existence of air at still greater heights. These meteors become luminous with the heat developed by comparison of the air in front of them, and presently evaporate. The absence of air means the development of no heat of compression, and as a consequence the emission of no light. Just as soon as the meteor can be seen, therefore, we know it has begun to collide with air particles or to have entered the earth's atmosphere, and a measurement of its distance from the earth, which has been found to be about 200 miles, gives the extent of an atmosphere of sufficient density to bring about these results.

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* Prof. Piccard and M. Kipfer, in a sealed car carried by a balloon, reached a height of nearly 10 miles on May 27, 1931, starting from Augsburg. On October 10, 1936, Lieut. Swain made the highest aeroplane ascent in Britain, establishing the world record for a height of 50,000 feet. Both these ascents—balloon as well as aeroplane—have since been exceeded as shown in Fig. 242. The statement of the highest mountain climb may also need revision. On June 8, 1924, the climbing party, consisting of Mallory and Irwin, who subsequently perished, were seen by Odell at a height which he estimated as 8610 m. (28,230 ft.) on Mount Everest.

A summary of the results of investigations showing the conditions in the upper air, *i.e.* above the stratosphere in the so-called ionosphere, is shown in Fig. 243.

37. WINDS

1. The cause of winds.—Open the door of a warm room very slightly, so that only a narrow chink is left (Fig. 245). Then hold a lighted taper to the chink, first near the floor and then higher and higher until it is at the top. Describe the behaviour of the flame. Test the chink at different heights with a thermometer. How do you account for the draughts?

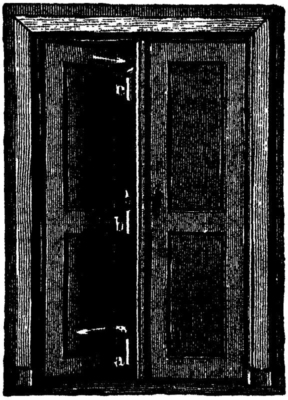


FIG. 245.—Experiment illustrating the cause of winds.

2. Direction of the wind.—(*a*) Estimate the direction of the wind by the weathercock, or by the drift of smoke, if any, at the same hour each day for a month, and keep a record. At the end of the month represent the result by a diagram (called a " wind rose ") as follows : Draw lines through the same point at angles of 45° and mark them N., N.E., E., S.E., S., S.W., W., N.W. to indicate the points of the compass. Make the length of each line, measured from the centre, proportional to the number of observations of winds blowing *from* that direction, during the month, letting, say, ¼ inch represent one observation. Draw a separate horizontal line of length to show the number of observations of " calm ". Draw a similar wind rose for each month in the year.

Add up the total number of observations of each wind direction during the year, and calculate what percentage it is of the whole number of observations ; make a diagram of the results of the year's observations, letting ¼ in. indicate one per cent.

(*b*) From the information given in the annual reports published by the Meteorological Department of the Government of India draw diagrams for January, April, July, October and the whole year, of the percentages of wind direction of the station nearest your district, and compare the results with your own observations. Is the topography of your district likely to modify the direction of the wind very much?

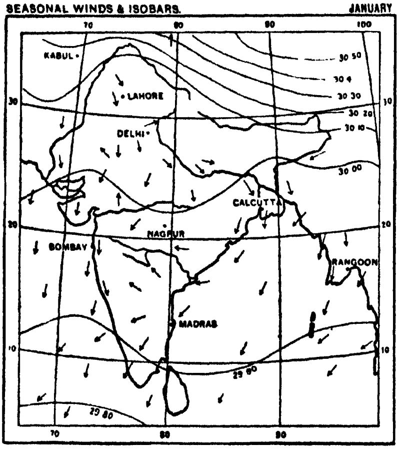


FIG. 246.

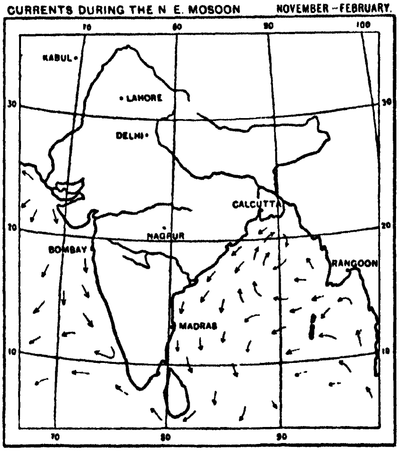


FIG. 247.

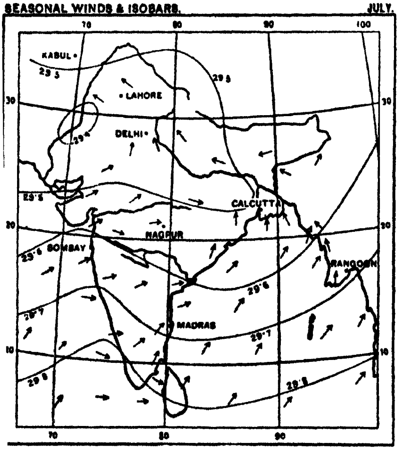


FIG. 248.

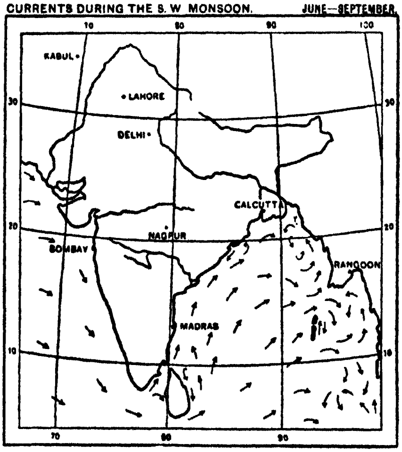


FIG. 249.

(*c*) What is the *prevailing* wind direction at each station given below, (i) in each month given, (ii) during the year as a whole? Karachi, Bombay, Madras, Kodaikanal, Poona, Nagpur, Calcutta, Patna, Shillong, Lucknow, Agra, Delhi, Peshawar and Lahore.

3. Wind direction and weather.—With what types of weather are the various wind directions usually associated in your neighbourhood? Note the character of the weather daily by the abbreviations used in the Daily Weather Reports :

b.	blue sky ;	*bc.*	sky half clouded ;
c.	sky three parts clouded ;	*d.*	drizzling rain ;
e.	wet air, without rain falling ;	*f.*	fog ;
g.	gloomy ;	*h.*	hail ;
l.	lightning ;	*m.*	misty (hazy) ;
o.	overcast ;	*p.*	passing showers ;
q.	squally ;	*r.*	rain ;
s.	snow ;	*t.*	thunder ;
u.	ugly, threatening ;	*v.*	visibility, unusual transparency ;
w.	dew ;	*x.*	hoar frost ;
z.	dust haze, or smoke.		

Mark the various wind directions in each of your monthly " wind roses " with the letters you have found to be most applicable to them during the month.

4. Observations of strength of wind.—Estimate the force of the wind daily and note it by the Beaufort number, of the scale of wind force, according to the following table :

Force	0	Calm - - -	- 0 to 5	miles	per	hour.
,,	1	Light air - -	- 6 to 10	,,	,,	,,
,,	2	Very light breeze	- 11 to 15	,,	,,	,,
,,	3	Gentle breeze -	- 16 to 20	,,	,,	,,
,,	4	Moderate breeze	- 21 to 25	,,	,,	,,
,,	5	Fresh breeze -	- 26 to 30	,,	,,	,,
,,	6	" Half a gale " -	- 31 to 36	,,	,,	,,
,,	7	Moderate gale -	- 37 to 44	,,	,,	,,
,,	8	Fresh gale -	- 45 to 52	,,	,,	,,
,,	9	Strong gale -	- 53 to 60	,,	,,	,,
,,	10	" Whole gale " -	- 61 to 69	,,	,,	,,
,,	11	Violent storm -	- 70 to 80	,,	,,	,,
,,	12	Hurricane -	- over 80	,,	,,	,,

Or make use of the following scale in estimating the force of the wind :

0. Calm, smoke rises vertically.
1. Light, 2 to 5 miles per hour, smoke deflected, wind vane moves.
2. Moderate, 7 to 10 miles, moving leaves, swaying branches, blowing up dust.
3. Brisk, 18 to 20 miles, swaying trees, blowing up twigs.
4. High, 27 to 30 miles, large trees sway, walking inconvenient.
5. Gale, 45 to 50 miles, breaking branches, loosening bricks, walking very difficult.
6. Hurricane, 75 miles or more, dismasting ships, unroofing buildings, and similar structures.

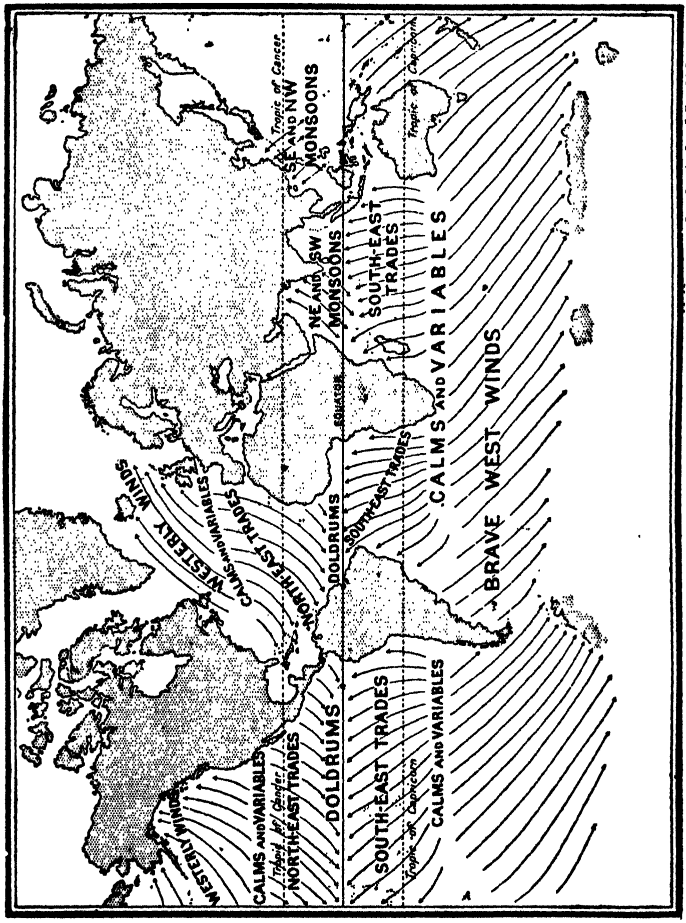
General remarks.—That the air is in movement is a fact of common knowledge. The results of its motion can be seen by watching the branches of trees swaying to and fro. The impact of the air particles upon the face can be felt by turning towards a strong breeze. Is there any regularity or order in the way in which winds blow? What causes them? These and a host of other questions present themselves here. Before attempting an answer to such queries, it will be convenient to direct attention to the way in which winds are named. In describing the direction of ocean currents, a northerly current is one which flows toward the north, or similarly with any other. But the contrary is true of winds.

The direction of an ocean current is always given as that point of the compass to which it flows, whereas that of a wind is always spoken of as that from which it blows.

The cause of winds.—Water always flows from a place of high pressure to one where the pressure is lower. It " seeks its own level ". Similar movements take place in all liquids and gases; there is in every case a movement from a point of higher to one of lower pressure until the pressure is equalised. But the pressure of the atmosphere varies from place to place, and since air is a fluid there naturally is a disturbance of the whole, resulting from the readjustment of pressure. *The air moves from the places where the pressure is high towards those spots where the pressure is low.* These movements constitute winds. The winds are *permanent* if the difference of pressures causing them continues throughout the year. They are *periodic* if the pressure differences only arise at definite intervals. *Variable* winds result from any pressure disturbance which may ensue from local peculiarities of situation or from any other cause. Variations in pressure are the results of **alterations in temperature** and of the increase or decrease of the amount of water vapour held by the air. These alterations are, in consequence, to be regarded as the primary causes of winds.

The surface pressure of the atmosphere is least (1) just north of the equator, (2) approximately along the Antarctic Circle, (3) along an ill-defined and varying line bordering the Arctic Ocean on the south. **The districts of greatest surface pressure** occur approximately along lats. 35° N. and 30° S. respectively (Fig. 255); they are known as the *horse latitudes.* The position of these belts of high pressure is apparently a result of mechanical forces set up by the earth's rotation. It is manifest that there will be a movement of air from the belts of high pressure towards those of low pressure. In the northern hemisphere, winds will blow from the northern belt of high pressure towards the equator, and from the same belt towards the pole; while in the southern hemisphere there will be winds towards the equator from the corresponding "horse" latitude, and from the horse latitude to the Antarctic Circle. Similarly, there will be outward currents from the poles to the low-pressure belts girdling them.

The trade winds.—The *directions* of these winds are modified, however, by the earth's rotation. The poles are at rest while places on the equator are performing a journey of 25,000 miles in 24 hours, that is, are moving with a velocity of over a thousand miles an hour. Other places on the surface have a velocity intermediate between these two extremes and dependent upon their latitude. Bearing this in mind, we must refer back to the wind in the northern hemisphere, which blows between the northern high-pressure belt and the equator and would be a north wind were the earth at rest. The air moving towards the equator is subjected to two velocities—(1) that which it has in a southerly direction, depending upon the actual pressure-difference between the place from which it starts and that towards which it moves; (2) that which, as a part of the rotating earth, it has from west to east. But as it travels towards the equator its west to east velocity becomes increasingly less than that of the sea and land beneath it, and its effect on the surface is the same as if it blew from east to west—just as a man travelling in a motor-car in the same direction as a wind moving with lower velocity feels the wind blowing in his face. The resultant effect of the two velocities—one actually from the north, and the other relatively from the east—is apparent in the **north-east** winds which are more or less permanent



Stanford's Geog^l Estab^t London

FIG. 250.—The permanent winds of the World.

between about lat. 35° N. and the equator. They are known as the **Trade Winds.** They blow with great constancy across the oceans, but are more or less interfered with over the continents, since the local conditions on the land vary considerably from place to place.

By applying the same reasoning to the southern hemisphere it will be clear that the direction of the trade winds south of the equator will be **south-east.**

The trade winds do not blow between the same latitudes in different oceans of the same hemisphere, nor between corresponding latitudes in the two hemispheres. Thus, in the Pacific Ocean the N.E. trades extend over the area between 6° N. and 25° N. latitude, while in the Atlantic they are felt between 7° N. and 35° N.

The south-east trade winds of the southern hemisphere blow between 2° N. and 21° S. latitude in the Pacific, and between 3° N. and 25° S. latitude in the Atlantic Ocean. These limits are not fixed throughout the year, but vary more or less with the seasons.

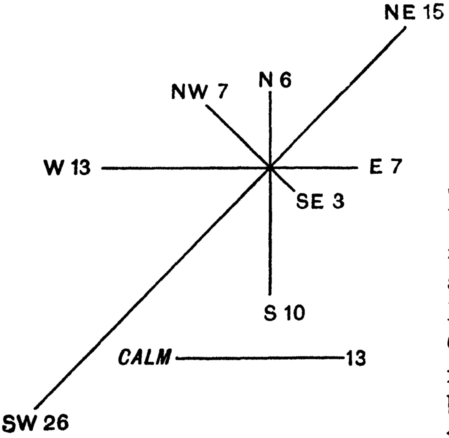


FIG. 251.—" Wind rose " for the year at Ramsgate. For explanation, see text.

Prevailing westerly winds.—What becomes of the winds blowing from the high-pressure belts towards the poles? The air which moving north-polewards is under the influence of two velocities, one urging it from the south and produced by the pressure-difference existing between the two places ; the other tending to make it move from west to east with the rotating earth. The second of these becomes increasingly *greater* than the rotational velocity of the earth beneath, since the wind has come from more equatorial regions with a correspondingly higher rate of speed. For reasons similar to those already given, the resultant velocity will be in an intermediate direction, and the wind will appear to come from the **south-west.** It is these winds in the **northern hemisphere** which constitute the **prevailing winds** in Great Britain as well as in other countries in the same latitudes. A study of Fig. 271 shows that although local and temporary variations in wind direction exist in the British Isles, westerly and south-westerly winds predominate in those islands at all seasons of the year. Fig. 251 shows diagrammatically the percentage number of winds blowing from various directions at Ramsgate during the year.

In the southern hemisphere the corresponding winds will manifestly blow from the north-west; they are of much greater importance in these latitudes than in those north of the equator. Their course is across oceans which interfere with their permanent character very little. They are spoken of as the **Brave West Winds,** and the latitudes in which they blow are known as the **Roaring Forties.**

The direction of these winds is contrary to that of the trade winds themselves, and to mark this fact they are sometimes called the **Anti-trades.** This name, however, is often given to those upper currents of air which blow in the atmosphere over the trade winds. These upper winds are the completion of the great convection currents which constitute the winds, for we cannot have a current in one part of a continuous fluid without causing one in other parts.

Circumpolar winds.—The currents of air from the south polar regions, towards the low pressure " trough " which approximately coincides with the Antarctic Circle, are deflected by the rotation of the earth into easterly and south-easterly winds. In the northern hemisphere, the very irregular distribution of land and water areas within the Arctic Circle interferes greatly with the regularity of the pressure distribution and resulting winds, but the general direction of flow is outwards from the pole.

Ferrel's law.—The modification of wind directions by the earth's rotation is merely one example of a general truth summarised in the statement known as **Ferrel's Law** : *If a body moves in any direction on the earth's surface, there is a deflecting force arising from the earth's rotation which tends to deflect it to the right in the northern hemisphere, but to the left in the southern hemisphere.*

Belts of calms.—Zones in which there is little horizontal circulation of the atmosphere occur round the earth in certain latitudes. One of the most marked is the low-pressure belt **just north of the equator** (p. 445). It owes its existence to the high temperature of the earth's surface along this belt, which causes the overlying air to expand and rise, its place being taken by air flowing in from the north and south as the trade winds. Along this belt, therefore, the general direction of the air flow is *vertically upwards.* The resulting belt of calm is marked, amongst other things, by the great rainfall which occurs there. It is often referred to as the **Doldrums.**

Other belts of calms occur in both hemispheres in the regions of lat. 30°–35° and are referred to as the **horse latitudes** or—not very accurately—as the **Calms of Cancer** and **Capricorn** respectively. It is in these latitudes that the *upper* currents corresponding to the trades and to the westerly winds of temperate zones come into contact moving in opposite directions and are mutually compressed. The air naturally *descends* to the surface of the earth, as a result of its increased density, which also raises its temperature and therefore increases its relative dryness (p. 407). It is significant that most of the dry deserts of the earth (Fig. 263) occur in or near the horse latitudes.

The " calms " should be thought of as places where no permanent winds occur, rather than as districts of absolute rest, for they are subjected to **variable winds** caused by local variations of pressure. The only other similar districts where such calms are prevalent are in the immediate vicinity of the poles, where the earth has little rotational velocity.

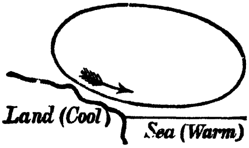


FIG. 252.—Land breeze.

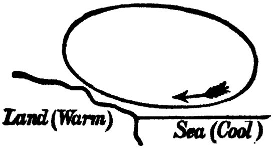


FIG. 253.—Sea breeze.

Land and sea breezes.—Near the sea, especially in the tropics, there are well-marked breezes, which result from the different heating effect of the sun's rays on land and water. Water has a higher specific heat, and is also a poorer absorber of heat, than land, and consequently during the day the air above the land gets warmer than that above the water, and an upward current of air is set up over the land. The cooler air from over the sea flows in to take the place of the air which rises, and constitutes a **sea breeze**. After sunset both the sea and land begin to radiate their heat ; the land, being a better radiator, cools quickly, but the sea remains warm. The air over the water consequently gets warmer than that over the land, and the pressure above the sea is lower than that over the land, causing a current of air from the land out to sea, which is known as a **land breeze**.

Dust storms.—Dust storms, though common in many parts of India, are particularly troublesome at times in Sind and Upper India. They are due to convection currents set up in dry air and accompanied by a very high electric tension. Many originate in wide arid plains, evidently the result of the rarefication of the air by long-continued heating of the ground surface. They occur at any hour, usually about sunset, and may travel at 40 to 60 miles an hour. A description by Dr. Baddeley (*Jour. As. Soc.*, Bengal, vol. xix, 1852) is as follows :

" The sky is clear and not a breath moving ; presently a low bank of clouds is seen in the horizon, which you are surprised you did not observe before. A few seconds have passed and the cloud has half-filled the hemisphere ; and now there is no time to lose—it is a dust-storm, a helter skelter, everyone rushes into the house in order to escape being caught in it . . . a broad wall of dust observed advancing . . . the whole atmosphere is filled with dust . . . the barometer rises steadily throughout . . . the storm is followed by a considerable reduction in temperature even if no rain falls."

North-Westers.—The North-Westers of Bengal are akin to the summer storms common in Europe, but are generally more violent. Before such a storm in Calcutta, in March, April and May, a low bank of clouds is almost always visible to the west and north-west in the afternoon, and the **nor-wester** is heralded by a sudden rise of the barometer. There is a strong stormy wind which blows outwards from beneath the gathering storm cloud and always either seaward or from some point between east and round by north to south-west. These storms rarely, if ever, advance from the sea. The wind that precedes the downpour is very cool and may cause the thermometer to sink 20° F. in 10 minutes on its approach. It raises clouds of dust and blows in gusts, often with great force. Hail rarely falls.

H. F. Blanford, the Father of Indian meteorology, wrote as follows on the characteristics of Indian meteorology : " We must dismiss from our minds much that constitutes the mental stock in trade of the European meteorologist. Of polar currents we know nought in India. Violent storms, other than north-westers and similar local disturbances, are, with us, rare and exceptional phenomena, not familiar and frequent visitants ; and instead of their coming upon us unawares from regions beyond our ken, at uncertain times and seasons, we can tell beforehand what is the numerical probability of a storm in a given month, and we might watch their generation and growth and decay and final extinction all within the area of our possessions and their included seas."

Monsoons.—In the account of the trade winds no reference was made to the Indian Ocean, because the conditions here change periodically as a result of the nearness of the continent of Asia and of the apparent annual motion of the sun. The name **monsoon** is itself derived from a Malay word meaning a *season*, to mark the fact of the periodical change in the direction of the winds, that is, the seasonal variation which they undergo.

According to H. F. Blanford :

" The primary cause of the arrival and reversal of the monsoons is the variation of the quantity of solar heat received by the land surface of India, according as the sun is in north or south declination.

" The quantity of the sun's heat incident at any given moment on a given area is inversely as the square of the distance from the sun ; and disregarding atmospheric absorption, directly as the sine of the sun's altitude " (Fig. 254).

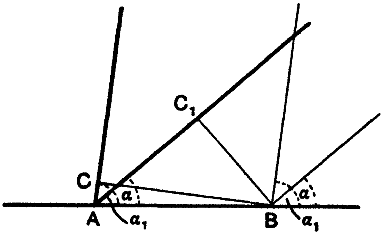


FIG. 254.

In Fig. 254, AB is the earth's surface,
AC_1 direction to sun when south of the equator,
AC ,, ,, ,, north ,, ,,
thus $CB = AB \cdot \text{sine}\ \alpha_1$ and $C_1B = AB \cdot \text{sine}\ \alpha$.
whence $CB : C_1B :: \text{sine}\ \alpha_1 : \text{sine}\ \alpha$.

The Tropic of Cancer passes 60 miles north of Calcutta and the sun is vertical on it at noon on June 21 and at 43° 5′ at noon on Dec. 21. Hence the quantities of heat received on a level surface at these two instants is as sin 90° : sin 45° 5′ : : 1 : 0·683. This ratio is diminished to nearly 1 : 0·730, owing to the greater distance of the sun at mid-summer than at mid-winter, due to the eccentricity of the earth's orbit.

In the hot weather and rains or summer—as a consequence of the inclination of the earth's axis—the heat equator (p. 388) migrates northward, especially over the great land masses, and the plateaux of central Asia receive a greater amount of heat from the sun than the waters of the Indian and Pacific Oceans nearer the equator. Since even an equal amount of heat is sufficient to raise the temperature of the land higher than that of the sea (p. 378), it is easily understood that the summer of central Asia is very hot indeed. The heated air naturally rises because of the decrease in its density, and cooler air from the south and east flows towards the area of low barometric pressure (29·4 inches in Turkestan in July) thus produced.

The north-east trades, which otherwise would blow over the Indian Ocean north of the equator, are entirely overcome and lost in this powerful wind northward; while the south-east trades are drawn across the equator and deflected to the right, in accordance with Ferrel's law (p. 448), to blow over India from May to September as the south-west monsoon. Over low lands this summer monsoon is a dry wind, but where forced into the upper air by encountering the Western Ghats and the Himalayas, it is cooled by expansion, and deposits its contained moisture as heavy rain.

The trade winds of the western Pacific also are affected in summer by the low barometric pressure over central Asia, and are so deflected that they blow over China as a south-east monsoon.

In cold weather or winter the heat equator has migrated southward, and the conditions have become reversed. Northern Australia is now a centre of high temperature and low pressure (29·7 inches or less), while central Asia is a region of excessive cold and high pressure (reaching 30·5 inches in Mongolia). As a consequence the winter monsoon over India blows from the north-east, over southern China from the north, and over northern China and Japan from the north-west. Drawn by the low pressure in Australia, the north-east monsoon blowing over the Indian Ocean is deflected to the left of its course after crossing the equator, and reaches northern Australia as the rain-bearing north-west monsoon.

The monsoon effects which occur—to a much smaller extent—in certain other parts of the world (*e.g.* the Guinea coast of Africa, Madagascar, Brazil, and even Spain) are to be explained on similar principles.

Seasonal distribution of pressure.—The distribution of the *permanent* winds has been seen to depend upon the respective positions of permanent high and low pressure belts, which can be studied in a map showing the average distribution of pressure throughout the year. On the other hand, the *seasonal* variations in wind direction, known as monsoon effects, depend upon seasonal variations in pressure. The extreme limits of pressure variation, like those of temperature variation, are reached in January and July, and therefore maps of January and July isobars (Figs. 246 and 248) are most useful in the study of monsoons.

Such maps show that over the northern continents * the atmospheric pressure is greatest in January, and greater over the land masses (where the temperature is lowest) than over the oceans (which are then warmer than the land). In the southern hemisphere at the same time the conditions are reversed. Further, since the greatest temperature ranges occur over the land, greater seasonal variations in pressure are also experienced by the continents than over the oceans. In addition, such maps of January and July isobars display very clearly the essential constancy of position of those high and low pressure belts which determine the course of the permanent winds.

The following scheme displays the respective directions of the **permanent** or " planetary " **winds** :

Region (approximate).	Pressure.	Direction.	Common Name.
N. Pole - -	High		
	↓	Irregularly outward from North Pole	
Low pressure areas of N. Atlantic and N. Pacific -	Low	Variable winds	
	↗	Variable W. and S.W. winds	" Westerly variables "
Lat. 35° N. -	High	*Calms* and variable winds	" Horse latitudes "
	↙	N.E. and E. winds	" Trades "
Equatorial Belt	Low	*Calms* and variable winds	" Doldrums "
	↖	S.E. and E. winds	" Trades "
Lat. 30° S. -	High	*Calms* and variable winds	" Horse latitudes "
	↘	Strong W. and N.W. winds	" Brave west winds "
Antarctic Circle	Low		
	↖	S., S.E. and E. winds	
S. Pole - -	High		

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* It is remarkable that over the North Atlantic and North Pacific the pressure is greatest in summer.

The monsoons of southern and eastern Asia may be tabulated as follows :

Season	Neighbouring region of highest pressure	Neighbouring region of lowest pressure	Monsoons over Indian region	Moonsoons over East Indies
May to Sept.	South Indian Ocean	Turkestan	W. and S.W.	S.E.
Sept. to May	Mongolia	North Australia	N.E.	N. and N.W.

Hurricanes.—Hurricanes and typhoons are often regarded as being those storms which occur in the West Indies and China Seas respectively, but the term is here used in the sense of a **storm,** which may occur in any part of the world. The term **Cyclone** was first coined for similar storms in the Indian Ocean, and particularly in the Bay of Bengal, by H. Piddington, of the Asiatic Society of Bengal. A **hurricane** or **typhoon,** or the **cyclone** of the Bay of Bengal, may be defined as a large stormy area, often more than a hundred miles in diameter, within which violent winds circulate round a centre to a height of perhaps 15,000 feet. The centre of a hurricane is a calm region. The cyclone is a spiral circulation of the winds around a region of low barometric pressure. It differs from a tornado chiefly by its greater size and duration. Both consist of an atmospheric vortex, a whirlpool of air moving upwards. The winds move inwards towards the centre.

A **tornado** is similar in constitution to a hurricane, but much smaller—a mile or less in diameter—and more violent. In India they often originate as **water-spouts** over rivers. If for any reason an area is developed in which the pressure is small, the air round this extent of low pressure will flow in to take its place. The force of the currents inwards depends upon the difference of pressure between the air of this area and that outside.

The following extract from the *South Indian Ocean Pilot,* 5th Edn., 1934, p. 16, shows that the term Cyclone is still employed by navigators of the Indian Ocean for hurricane storms, although the term Cyclone appears to be extended by meteorologists to such weather disturbances of temperate regions as will be considered in the next section :

" In a cyclone in the southern hemisphere the winds circulate round the centre in the same direction as the hands of a watch, with a spiral movement incurving towards the centre. The winds increase in strength from the exterior immediately to the edge of the central calm area: the barometer falls rapidly towards the centre, its lowest value being usually from 30 to 60 mb. (0·9 to 1·8 in.) below that outside the cyclone. In the centre the wind may drop to complete calm, or may be light and indefinite; the sea, however, remains dangerously high and confused on account of the hurricane winds at no great distance. The passage of the central calm, in general, occupies only 20 to 40 minutes. Once out of the calm the previous succession of events is repeated in reverse order. If the wind ceases suddenly, it will recommence suddenly. Outside the central area the sky is completely overcast and torrential rain falls, while in the central calm, the rain ceases and the clouds disappear more or less completely. Most of the storms are not accompanied by electrical phenomena, but occasionally thunder and lightning have been observed and in almost all such cases the occurrence has been on the northern side of the storm field; hence it portends the passing away of the storm."

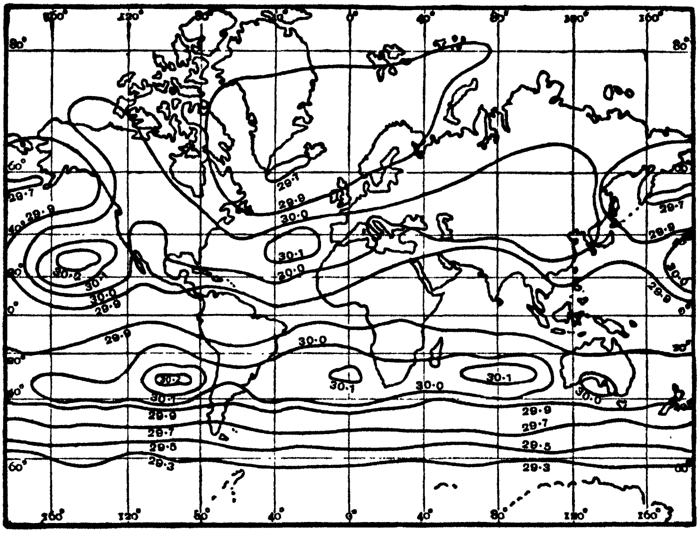


FIG. 255.—The average distribution of atmospheric pressure throughout the year.

38. CYCLONES AND ANTI-CYCLONES

1. **Isobars.**—*An isobar is a line joining places along which the sea-level air-pressure is the same.* The corrected height in inches of the barometer at 8 a.m. (I.S.T.) on July 1, 1936, at the following places was :

Calicut (Malabar)	29·81	Calcutta	29·50
Tuticorin	29·83	Patna	29·53
Colombo	29·81	Ranchi	29·45
Port Blair	29·73	Delhi	29·46
Mergui	29·89	Nagpur	29·55
Rangoon	29·71	Bombay	29·63
Akyab	29·61	Quetta	29·40
Chittagong	29·55	Kabul	29·53

Mark these places and pressures on an outline map of India. Draw a straight line joining Colombo and Nagpur; $29{\cdot}81 - 29{\cdot}55 = 0{\cdot}26$; therefore, at a point *A*, $\frac{1}{26}$ of the distance from Colombo to Nagpur, the pressure is probably 29·80″. A point *B*, $\frac{11}{26}$ of the distance from Colombo to Nagpur marks the position of 29·70″, and a point *C* $\frac{5}{26}$ of the distance from Nagpur to Colombo is roughly the position of 29·60″. In a similar manner locate points on the isobars 29·80″, 29·70″, and 29·60″ between Mergui and Calcutta, and between Calicut and Quetta. With these points secured, it will be a simple matter to draw in the isobars lines for 29·80″, 29·70″, 29·60″, 29·50″ and 29·40″.

2. **Pressure gradient.**—In what direction was the line of greatest pressure-decrease (often called the line of pressure gradient) in India at the time? Estimate the pressure gradient in parts of an inch (of barometric height) per 100 miles between Calicut and Quetta. Is the gradient greater or less between Delhi and Colombo than it is between Calcutta and Mergui? The force of the wind at Calicut was 6 (see Beaufort scale on p. 443), and at Mergui 3. At which place would you have expected there to be the stronger wind? Why?

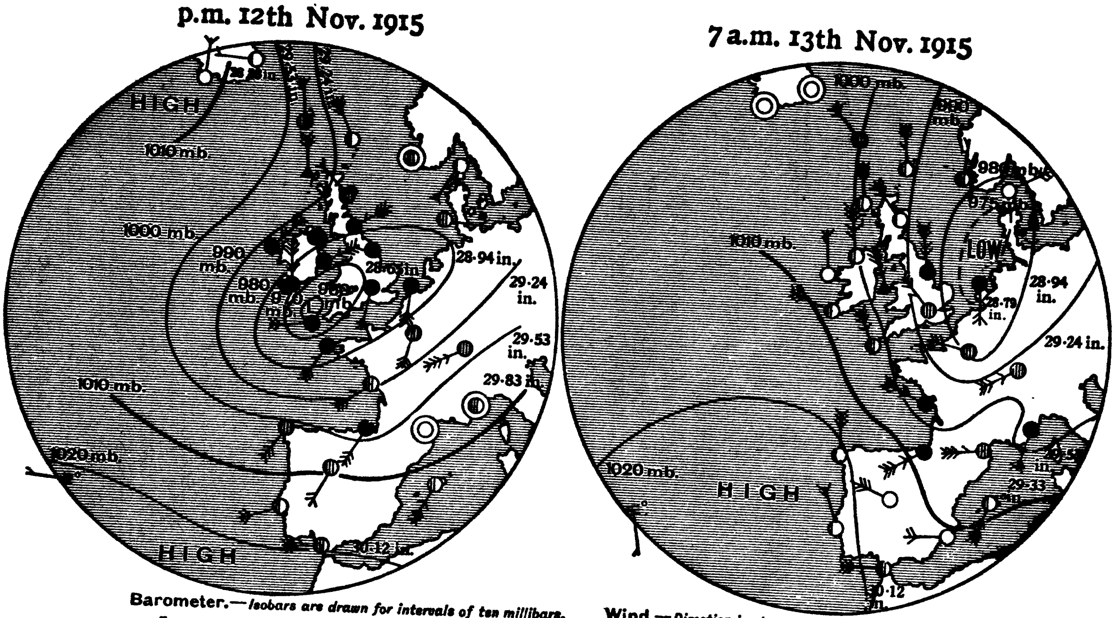
3. **Behaviour of a low-pressure system in water.**—Select a wash-hand basin which empties by a hole at the bottom. One in which the hole is near the centre is to be preferred. Or, better, a large flower pot may be used. Close the hole, fill the vessel with water, and then open the escape. Which part of the surface is highest as the water runs out? Which lowest? Why? Is the pressure of the water greater near the edge or near the centre? Why?

What currents can be detected at the surface? Does the outside water flow in a radial direction towards the centre, or does it describe spiral paths? Is the direction clockwise or anti-clockwise? Repeat the experiment several times to see if there is any constancy in the direction of the spiral when the flow is not interfered with. Can you easily give it any desired direction at the beginning of the flow? How? Make a diagram of the water as seen from above, representing differences of level by contour lines, and direction of flow by arrows. Are the arrows parallel to the contour lines or at a small or large angle? To what extent do these contour lines also indicate varying pressures? Can they be regarded as isobars?

4. **Whirlwinds.** (*Outdoor Work.*)—At the first opportunity make a note of the behaviour of any dry leaves, dust, etc., you may find being whirled round by the wind. In what direction do they move : clockwise or anti-clockwise? Describe any evidence that there is a vertically upward current in the whirlwind. At what part of the ground level of the whirlwind is the pressure lowest? Why do you think so? Does the whirlwind as a whole remain in the same place until it collapses, or does it move along? Does it move in the direction of the general wind current or not?

5. **Cyclones.**—*A condition of low atmospheric pressure in which the isobars form closed curves is called a depression or cyclone.* Examine Fig. 256. Where, at 6 p.m., November 12, 1915, was the highest barometric pressure in western Europe? Where was the lowest? What term can be used to describe the condition, of which this latter point was the centre? Why? Where is the pressure gradient greatest, and where least, in the sides of the depression? Do the winds blow on the whole along lines of pressure gradient (*i.e.* across the isobars), or along the isobars? Are they parallel to the isobars, or do they turn inwards or outwards? Is the resulting spiral in the clockwise or anti-clockwise direction? Imagine yourself standing—at any station where a wind arrow is shown—with your back to the wind ; is the pressure higher on your left or on your right?

State the position of the centre of the depression at 6 p.m. on the 12th and at 7 a.m. on the 13th of November. In which direction is it travelling? Estimate its speed. Which countries are respectively in front, in the rear, on the left and on the right of the moving depression? What are the wind directions in front, in the rear, on the right and on the left of the depression on the map? Tabulate and account for the wind



Barometer.—*Isobars are drawn for intervals of ten millibars.* **Wind.**—*Direction is shown by arrows flying with the wind. Force, on the scale 0-12, is indicated by the number of feathers.* *Calm* ◎ **Weather.**—*shown by the following symbols:*— ○ *clear sky.* ◔ *sky quarter clouded.* ◑ *sky half clouded.* ◕ *sky three-quarters clouded.* ● *overcast sky.* ● *rain falling.* ✱ *snow.* ▲ *hail.* ≡ *fog.* ≡° *mist.* T *thunder.* K *thunderstorm.*

FIGS. 256 and 256B.—A cyclone; maps showing the distribution of the pressure, wind and weather in western Europe at 6 p.m. on Nov. 12, 1915, and 7 a.m. on Nov. 13, 1915. (Reproduced, by permission of the Controller of H.M. Stationery Office, from "The Weather Map".)

directions, air pressures and weather, in two named stations selected by yourself, respectively north and south of the path of the depression :

		6 p.m. Nov. 12	7 a.m. Nov. 13
Station A.	Wind		
	Bar.		
	Weather		
Station B.	Wind		
	Bar.		
	Weather		

What information of the approaching depression might have been obtained at A and B from the change in wind direction?

What changes in wind direction do you suppose have taken place at stations on the " storm-track "? Examine Fig. 261 and say whether the winds of the depression are likely to be colder on its eastern or its western side. What changes of *temperature* are likely, in general, to precede and follow a depression? What are the wind directions at stations where rain is shown to be falling? What pressure changes will follow the changes of temperature (p. 438)? How is the barometric pressure altering (*a*) on the east (*b*) on the west of this depression? Will such pressure changes tend to make this depression travel eastward or westward?

How does the path of the depression agree with the direction of the prevailing winds of western Europe?

6. **Anti-cyclones.**—*An anti-cyclone is a condition of high atmospheric pressure in which the isobars form closed curves.* What is the highest pressure marked on Fig. 257? Where is it situated? Where is the pressure gradient greatest? What is its direction? Imagine yourself standing—at any station where a wind arrow is shown—with your back to the wind ; is the region of high pressure on your right or on your left? Combine this with the result of the similar observation in Expt. 5 above, and formulate a rule which is equally applicable to cyclones and anti-cyclones. Is the circulation of the winds in an anti-cyclone clockwise or anti-clockwise? The anti-cyclone is not a well marked feature in Indian weather conditions.

Weather charts.—With a view of ascertaining the conditions upon which the various types of weather depend, and therefore of discovering means of making weather forecasts, it has become customary to record the atmospheric changes which occur at the different observing stations scattered over the various countries of the

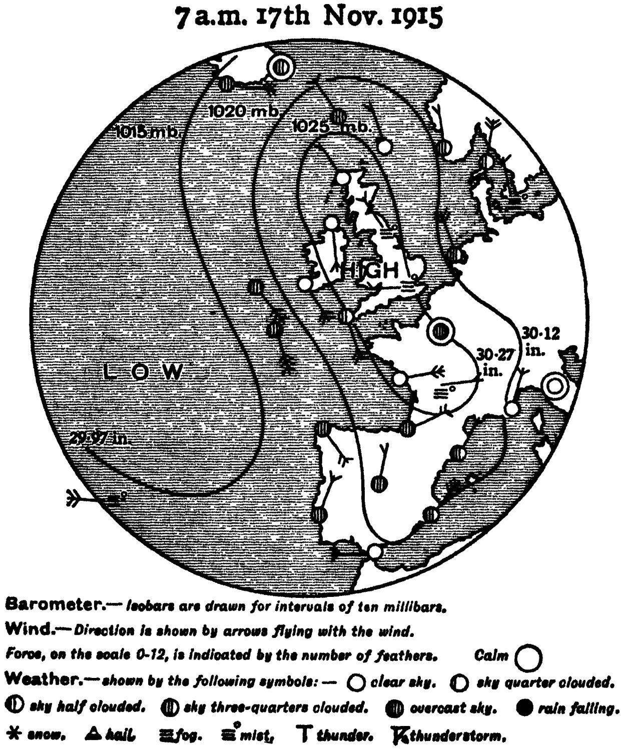

7 a.m. 17th Nov. 1915
1015 mb.
1020 mb.
1025 mb.
HIGH
LOW
29.97 in.
30.27 in.
30.12 in.
Barometer.—Isobars are drawn for intervals of ten millibars.
Wind.—Direction is shown by arrows flying with the wind.
Force, on the scale 0-12, is indicated by the number of feathers. Calm ○
Weather.—shown by the following symbols:— ○ clear sky. ◔ sky quarter clouded.
◑ sky half clouded. ◕ sky three-quarters clouded. ◍ overcast sky. ● rain falling.
✱ snow. ▲ hail. ≡ fog. ≡ mist. T thunder. T thunderstorm.

FIG. 257.—An anti-cyclone; map showing the distribution of the pressure, wind and weather in western Europe at 7 a.m. on Nov. 17, 1915. (Reproduced by permission of the Controller, H.M. Stationery Office, from the *Meteorological Glossary.*)

civilised world. These observations are recorded in different ways in the form of **weather charts**.

In India the most complete and valuable daily charts are those contained in the **Daily Weather Report** issued by the Meteorological Office, Alipore, Calcutta. The report includes such observations as those of the pressure, temperature and hygrometric state of the atmosphere ; the rainfall, the amount of bright sunshine, condition of the sky, the direction of the wind, and so on. A system of letters and symbols of fairly general application has grown up ; and a list of some of those used in Great Britain has been given on p. 443. A " synoptic " chart of a large part of southern Asia—showing the state of the barometer, the direction and force of the wind, the sea disturbance, the temperature of the air (by means of isotherms), the normal temperature of the sea for the current month (by means of a scale of tints), as well as areas under rainfall and notes of the weather generally—is given in each report. Other information supplied by the sheet consists of supplementary charts of " Barometer, wind and weather for 7 a.m. and 6 p.m. yesterday ", tables of the reports received from the various observation-stations, and from ships at sea (by wireless telegraph), notes on the weather of the same morning and previous day, a " general inference from the 7 a.m. observations," and a forecast of the following day's weather for each of the provinces into which India is divided for the purpose.

Other admirable charts, supplying much of the information just referred to, are contained in *The Times*, *Daily Telegraph* and other newspapers every morning for Great Britain and part of western Europe. In India *The Statesman* endeavours to follow this excellent example and publishes a map showing most of this meteorological information for India in general.

Isobars.—In the preparation of such weather charts the corrected barometer readings telegraphed every morning to the Meteorological Office in Calcutta are marked upon the map, at the points representing the positions of the various stations in India and the adjacent seas from which they are usually received, in the manner shown in Figs. 256 and 257. Lines called **isobars** are then drawn joining those places where the pressure * is the same.

These isobars are of the greatest value in enabling the meteorologist to study the distribution of atmospheric pressure over large areas. They are filled in for differences of 10 millibars, *i.e.* about

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* Pressures are stated in units called *millibars* (mb.), 1000 mb. corresponding to a barometer height of 29·5 inches.

0·03 of an inch in the barometric reading. If a line be drawn such that it is perpendicular to every isobar through which it passes, it will represent the direction in which the pressure is altering, or the line of **pressure gradient.** It is clear that the gradient is greatest where the isobars are closest, and it is here, naturally, that the force of the wind is usually greatest. The " steepness " of the barometric gradient may be expressed by the difference in pressure for a given unit of distance measured along the line of gradient.

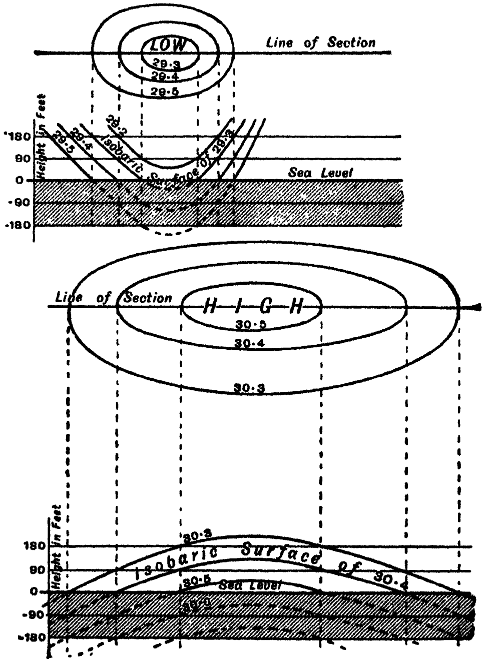

FIG. 258.—Isobars and isobaric surfaces of a cyclone (upper figure) and an anti-cyclone (lower figure).

Isobaric surfaces.—An isobaric surface is one which passes through points having the same atmospheric pressure. It cuts the sea level along the lines called isobars. The isobaric surface of 29·9 inches (*e.g.*) reaches sea level along the isobar of 29·9 inches, but is above sea level where the sea-level pressure is more than 29·9 inches. In regions of high pressure, therefore, the isobaric surfaces are dome-shaped; in regions of low pressure they are basin-shaped, as will be clear from Fig. 258.

Movements of the air in cyclones and anti-cyclones.—A wind always blows from a place where the pressure is high to one where it is lower, and the force of such a wind depends upon the rate of the difference in pressure between the two places, that is to say upon the barometric gradient. Moreover, a study of the direction of the wind side by side with the distribution of the isobars reveals the fact that the wind moves along lines which are nearly coincident with the isobars, but which tend to cross from the higher to the lower ones. It soon becomes evident, if the isobars are drawn regularly for consecutive diurnal observations of pressure, that the isobars often take the form of *closed curves* which include **an area of low barometric pressure.** Consequently, from what has been just remarked about the direction of the winds compared with the isobaric lines, it follows that the winds are also moving in curves roughly coincident with the lines of equal pressure. Such a condition of things (Fig. 256), where a district of low pressure is surrounded by zones of higher pressure, constitutes what is known as a **cyclone** or **depression**; or in America as a *low*. The curved path which the wind follows in such a cyclone is really a left-handed spiral which results from the rotation of the earth affecting what might otherwise be a simple radial motion of the wind towards the centre of the low-pressure area. Though this **anti-clockwise** motion characterises the cyclones in the northern hemisphere, the direction is clockwise in the southern hemisphere. The ultimate result of cyclonic movements is the formation of an upward current of air above the central low-pressure area, with the consequent tendency for air to flow from the regions around to take its place. The ascending air in the middle of a cyclone—as elsewhere—expands as its pressure decreases. The expansion is accompanied by cooling which causes condensation of its moisture in the form of **rain,** sleet or snow (Fig. 256). The wind in the centre of a cyclone is generally very slight.

The form assumed by the isobars, at some periods of observation, reveals a condition of things exactly opposite to that in a cyclone, *viz.*, a **high-pressure area** surrounded by belts of lower and lower barometric pressures (Fig. 257). Such a phenomenon constitutes an **anti-cyclone.** In anti-cyclones in the northern hemisphere the air movements take the form of right-handed outward moving spirals,

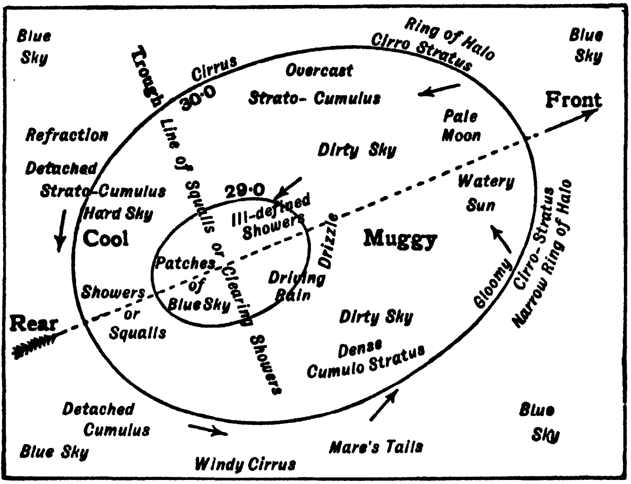

FIG. 259.—Weather conditions accompanying a cyclone (Abercromby and Marriott).

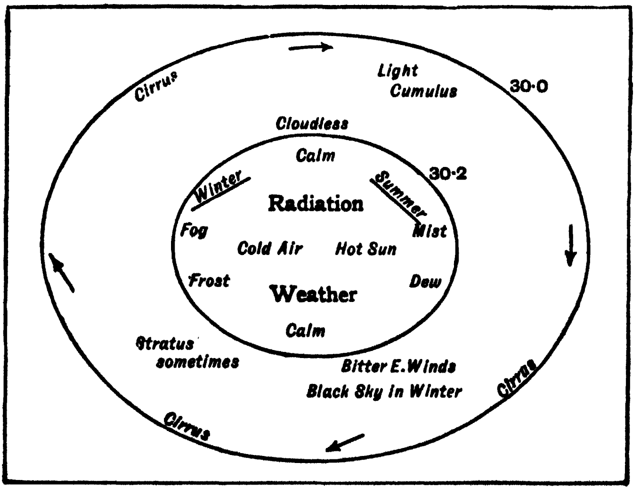

FIG. 260.—Weather conditions accompanying an anti-cyclone (Abercromby and Marriott).

or, in other words, the winds move in a **clockwise** manner. It has been found, too, that the winds are generally stronger in cyclones than in anti-cyclones.

The anti-clockwise movement of the winds of a cyclone, and the clockwise direction of those of an anti-cyclone are both conveniently expressed in **Buys Ballot's Law**: *In the northern hemisphere a person standing with his back to the wind has the lower pressure on his left hand.** The law indeed applies to winds generally. It is plain that as a cyclone travels along the earth's surface, the winds at places affected by it must change in direction to assume their appropriate relation to the shifting area of low pressure. Indeed a change in the direction of the wind at a place often heralds the approach of a cyclone before the barometer has begun to fall.

The average height of a cyclone is only about 6 miles, but its superficial extent is sometimes very great, reaching in some cases a thousand miles across; there is always a tendency for such extensive cyclones to subdivide into smaller ones. Usually one of the subdivisions is a cyclone of greater intensity than the others, and its intensity generally increases gradually to a maximum, while the others disappear. Another point of interest is that the cyclone is often drawn out, as it were, in one direction, making its form oval, with the longer diameter at least half as great again as the shorter.

The rate of advance of a cyclone varies within very wide limits. Details of many cyclonic storms are given by Sir John Eliot in his " Handbook of Cyclonic Storms in the Bay of Bengal ", 1890. The greatest intense storm on record is that of the Backergunge cyclone of October 28-31, 1876. It was heralded two years before by another intense storm—the Midnapore cyclone—of October 13-15, 1874. An extensive, and perhaps a more violent storm, which did a great deal of damage to shipping, was the Calcutta cyclone of October 2-5, 1864. A less extensive but perhaps the most violent storm was the False Point cyclone of September 19-22, 1885, when the lowest barometric reading (27·135″) ever taken at sea in the tropics was recorded. A typical cyclone, prolonged in violence, from June 26 to July 4, occurred in the Bay in 1883.

Almost all cyclonic storms in the Bay of Bengal originate or are produced in the Bay itself and travel north-westward into Bengal, Bihar and Orissa. They occasionally travel across the peninsula to the Arabian Sea. The Port Blair cyclone of November 1-7, 1891, originated in the Gulf of Siam.

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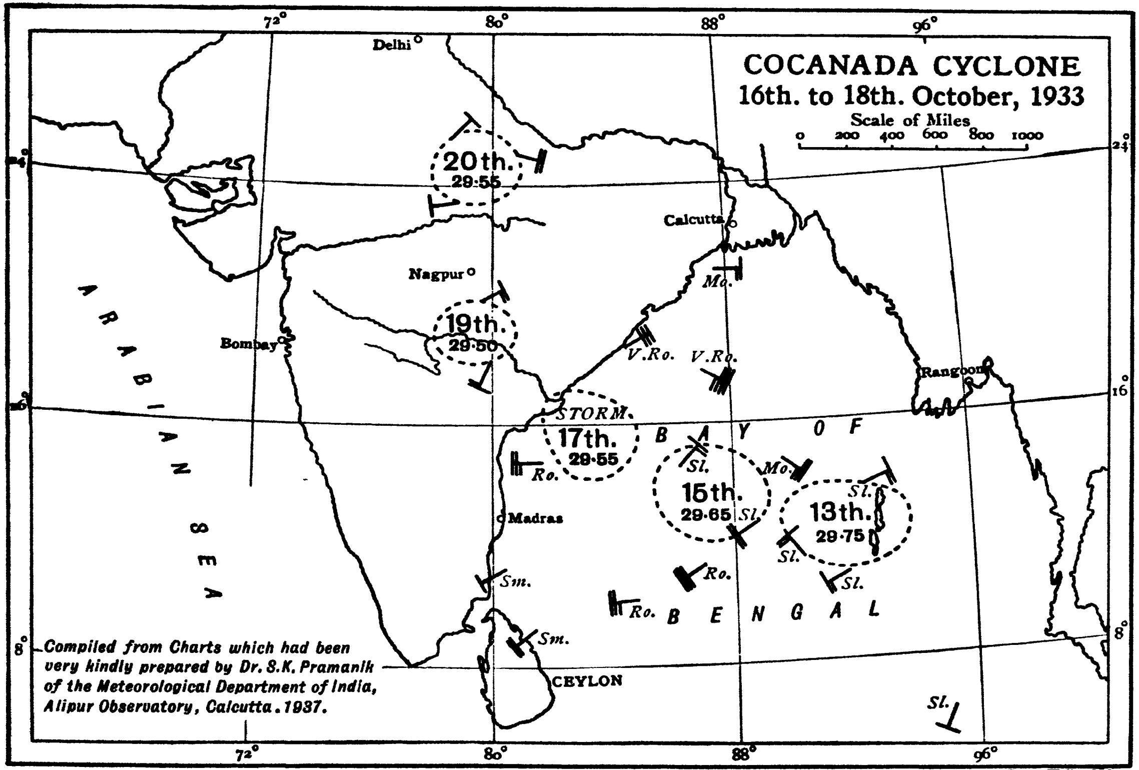
* If a line be drawn between the seats of highest and lowest pressure, the direction of the wind approaching this line will form an angle of 60° to 80° with it; the obtuse angle will be on the side of the lowest pressure.

The Cocanada Cyclone of October 17, 1933.—As an example of a typical Bay of Bengal cyclone that which struck the Madras coast between Cocanada and Masulipatam on October 17, 1933, may be given. Fig. 261, which has been compiled from the five charts carefully prepared by Dr. S. K. Pramanik, Indian Meteorological Department, Alipur, shows the passage of this cyclone from the initiation of the depression over the Andaman Islands on October 13 to the Lucknow area where it filled up by October 22. Under the influence of this storm nearly general rain occurred in Bengal, Orissa and the north Madras coast with a few heavy falls in south-west Bengal, Orissa and the north Circars coast. The history of the storm is briefly as follows :

A shallow depression formed in the Bay of Bengal in the neighbourhood of the Andamans on the morning of October 13, 1933, around which the isobar stood at 29·75 inches. At that time a region of high pressure, above 29·85 inches, prevailed over northern India, including the Himalayas and Assam. An isloated area of high pressure was present in Hyderabad (Deccan) and another south of Cape Comorin, where the sea was very rough by shoreward winds. The sea was generally smooth in the Bay of Bengal except for slight seas off Sabang (Sumatra), Cape Negrais, Akyab, Vizagapatam and Madras, partly the result of off-shore winds. An area of low pressure (29·80 inches) was then present in the Arabian sea west of Mangalore and over part of the Laccadive Islands.

By the morning of October 15, the depression in the Bay of Bengal had moved west-north-west and isobar 29·65 inches covered an area in 13° to 14° N. and 87° to 88° E. By this time the winds had strengthened and rough seas were encountered north-east of Ceylon and off Cape Negrais, and the sea was rising off the Orissa coast about Gopalpur. The areas of high pressure over Hyderabad and Cape Comorin had disappeared, but the pressure region in the north persisted—especially in eastern Afghanistan and the Assam Himalaya.

On the morning of October 17 the storm which had already developed on the 15th had arrived off the coast at Cocanada, where the isobar was 29·55 inches. The storm centre was travelling north-westwards into Hyderabad. Rough seas prevailed along the Madras coast from Vizagapatam to below Madras, and very rough seas were to be met with from about 17° N : 87° E. across the Bay to Cape



Emery Walker Ltd. sc.

FIG. 261.

Negrais. There were slight seas in the Bay north-east of Ceylon. Regions of high pressure, above 29·85 inches, persisted in northern India—especially in north-east Afghanistan and the Bhutan Himalaya.

On October 19 the depression had entered Chanda in the Central Provinces with the barometer below 29·50 inches. The storm was then moving northward. At this time strong south winds were blowing up the Madras coast off which the seas were rough as far north as Puri and in the Bay east of Ceylon as well as at Colombo and Cape Comorin. The sea was smooth up the Tenasserim and Akyab coast as far as Chittagong, but a slight sea persisted at the Sandheads at the mouth of the Hooghly. The high pressure areas of the north were over the Punjab Himalaya and Upper Burma.

By the morning of October 20, the depression had reached Jhansi, where the isobar was 29·55 inches, and with evidence of filling up. The depression disappeared about Lucknow before the morning of October 22. An area of high pressure was present in South Afghanistan on October 20, and that of Upper Burma had extended southward to the Andaman and Nicobar Islands, where anti-cyclonic conditions had appeared on October 20. The seas in the Bay of Bengal were slight to smooth, but rough seas persisted at Cape Comorin and off Colombo.

Weather forecasting.—In the tropics or torrid zone, where there are north-east trade winds in the northern, and south-east winds in the southern hemisphere, blowing with great regularity, there are relatively few cyclonic disturbances compared with the conditions in middle latitudes of the so-called temperate zones.

It is said that on the average the weather of western Europe is under the influence of cyclones for more than 100 days in every year.

In middle temperate zones, where the prevalent winds are westerly, the areas of low or high pressure, as the case may be, move **from west to east** along certain more or less well defined tracks. The weather to be expected with the various types of cyclones and anti-cyclones is known (Figs. 259 and 260) from past observations; so that regular telegraphic information of the barometric and other conditions prevailing, especially to the westward, enables the Meteorological Offices of America and Europe to issue forecasts for two or three days ahead, which in a large majority of cases prove substantially accurate.

Comparison of cyclones and anti-cyclones.[*]**—**

CYCLONES	ANTI-CYCLONES
Winds	
1. Strong in force; at times severe gale, or hurricane.	1. Light in force, often calm.
2. In the northern hemisphere circulate left-handed round the centre of the system.	2. In the northern hemisphere circulate right-handed round the centre of the system.
3. Draw in spirally *towards* the centre.	3. Draw out *from* the centre towards the neighbouring cyclones.
Temperature	
1. Low in summer.	1. High in summer.
2. High in winter.	2. Low in winter.
Weather	
1. Rough and squally.	1. Quiet and dry.
2. Rain in summer, snow in winter, thunderstorms in both seasons, but especially in summer.	2. Cloudless and bright in summer, with haze at times; foggy or bright in winter.

The characteristic weather accompanying cyclones and anti-cyclones respectively is shown in more detail in Figs. 259 and 260.

The terms " cyclone " and " anti-cyclone " do not describe phenomena that can be observed by one observer or at a single station; they should, therefore, not be used in the description of local phenomena; they represent generalisations based upon the charting and study of winds and clouds observed at many stations, and should only be used when the nature of the rotation of the winds has been clearly demonstrated or can be safely inferred.

Recent researches show that the condition of things in the cyclone and anti-cyclone is not so simple as has been supposed. Many of the views which have been hitherto received have been modified, especially so far as anti-cyclones are concerned. Sir Napier Shaw pointed out that these " are not of single meteorological character. Local changes of many kinds may take place within them, and almost any kind of weather, except those which represent violent atmospheric changes, may be associated with their central regions ". The student who wishes to pursue the subject further should study the maps, etc., in Sir N. Shaw's little book " The Weather Map " (Meteorological Office, London, 3s.).

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[*] Gaster, *Q.J. Roy. Met. Soc.*, July 1896.

EXERCISES ON CHAPTER XIV

1. Explain the wind systems of the equatorial regions, showing the effect of heated land masses upon direction. Illustrate your answer by reference to South India and Ceylon, Nigeria, British East Africa and British Guiana.

2. Draw a map to show isobars and winds in a low-pressure system (cyclone) the centre of which (29 inches) is over the head of the Bay of Bengal, while the pressure in Calicut is 29·7 inches, in Port Blair 29·9 inches and in Rangoon 29·5 inches. If it is moving due eastwards, explain the changes of wind during the next twenty-four hours at Port Blair.

3. What is a monsoon wind? Explain the south-west monsoon of India. Draw a sketch-map to show to what parts of India it brings rain.

4. Explain fully how the direction of the trade winds is influenced by the earth's rotation.

5. What is atmospheric pressure, how is it measured and how shown on maps? Contrast the distribution of pressure over Eurasia in summer and winter respectively.

6 What are monsoon winds? Where, when, and from what directions do they blow? What parts of Asia receive rain from monsoon winds?

7. What are isobars, and how are they drawn on maps? Explain how by means of a map on which these lines are drawn we can approximately estimate the force and direction of the wind. Why is it preferable to have isobars drawn for January and July than for the whole year?

8. What are the characteristic features of (*a*) cyclonic and (*b*) anticyclonic weather?

State the probable weather changes which would be experienced in October at the mouth of the Hooghly when the central portion of a cyclone passes northward across the Sundarbans.

9. How are storms predicted in the British Isles? Illustrate by means of a diagram or chart.

10. Describe a typical cyclonic storm in the Bay of Bengal. State in what direction the winds would be to a ship proceeding to Madras from the Hooghly.

11. Where are the trade winds met with and how are they caused? How is the direction of a wind defined?

12. Point out the connection between areas of high and of low pressure and the direction of the wind. What influence has the rotation of the earth on winds? In what direction do winds blow that are most altered in direction thereby?

13. Give a description of the monsoons of the Indian Ocean and their influence on the ocean currents.

14. Describe and account for the belt-like arrangement of winds and calms over the earth.

15. Describe briefly a cyclone, a tornado, a norwester, and a dust storm. Draw special attention to the rise and fall of the barometer and of the thermometer in each case.

16. Draw or write a brief description of a weather map of a low-pressure system or cyclone, the centre of which is at Port Blair, where there is a pressure of 29·0 inches, while 600 miles in all directions the pressure is 30·0 inches.

17. On a given day a deep cyclone extends over the North Atlantic from Labrador to the British Isles, with its centre about midway between them. Draw a rough sketch of the storm area, showing the probable distribution of pressure and of wind direction. What sort of weather would you expect to find on the coasts of (*a*) Labrador, (*b*) the British Isles?

18. What are isothermal and isobaric lines? How do the directions of each alter in the northern hemisphere, as we pass from winter to summer, and why?

19. What are *monsoons*? Give their limits in Asia. Explain how they are formed, pointing out how the rotation of the earth affects them. Describe the kind of weather found at the changes of the monsoons in any part of Asia.

20. Describe a method of making a barometer. What advantage is there in using mercury as the liquid? Can any other be used? What is the approximate height of a mountain if a barometer on its summit stands at 27 inches when one at the sea level marks 30 inches?

21. Sailing ships go from England to New Zealand by the Cape of Good Hope, but return from New Zealand to England by Cape Horn. What are the geographical reasons which account for this difference in the outward and homeward routes?

22. Explain the distribution of pressure, winds, and weather in an anti-cyclone. Under what conditions does a lasting high-pressure area form over central Asia?

23. Explain how weather forecasts are made.

24. What weather is to be expected :

(*a*) When the wind is backing from the westward to the southward and the barometer has begun to fall?

(*b*) When the wind is veering from southward to westward and the barometer has begun to rise?

(*c*) When the wind is backing from south to east and the barometer is falling?

(*d*) When the wind veers from north to east and the barometer is falling ?

25. During the war the British Meteorological Office ceased issuing weather forecasts. Show how a knowledge of the weather conditions over the North Atlantic was of military importance to Germany.

CHAPTER XV

CLIMATE

39. THE CLASSIFICATION OF CLIMATES

1. **Sunshine zones.**—What are the limits of latitude in which the sun is

(*a*) sometimes vertically overhead ;

(*b*) never overhead, yet rising and setting every day ;

(*c*) sometimes above, and sometimes below, the horizon for more than 24 hours at a time?

How are these zones named in your atlas?

2. **Wind zones.**—Make a table showing approximately the limits of latitude in which prevail

(*a*) the trade winds ;

(*b*) the " westerlies " ; and

(*c*) the doldrums respectively (p. 448), and compare the zones with the sunshine zones. Shade the wind zones on an outline map of the world.

3. **Supan's temperature zones.**—Examine Fig. 263. Describe in words the course of the mean annual isotherms of 68° F., and of the isotherms of 50° F. for the warmest months of the northern and southern hemispheres. How do the belts thus marked correspond with the sunshine and wind belts? How do you explain the widening of the hot belt over the continents, and the greater width of the north " temperate " belt than the southern?

Climate.—By the word climate is meant the average condition of the weather. We have learnt that variations in the weather are chiefly due to the influence which changing **temperature** has upon atmospheric **moisture** and upon the movements of the air.

Sunshine zones.—Since the surface of the earth receives its heat from the rays of the sun, it was natural that the earlier systems of classifying climate should be based largely upon the amount of daylight which different parts of our planet receive throughout the year. The commonest of such systems is that in which the earth's surface is divided (Fig. 262) into

(1) a **torrid** or tropical zone lying between the tropics of Cancer and Capricorn, *i.e.* between lat. 23½° N. and 23½° S.;

(2) two **temperate** zones, lying between the tropic of Cancer and lat. 66½° N., and between the tropic of Capricorn and lat. 66½° S.; and

(3) the two **polar,** or "frigid" zones or "caps".

The torrid zone, in other words, is the zone including all places over which the sun is vertical twice in the year (p. 124); in the temperate zones the sun's rays are never vertical, but the sun rises and sets once in every 24 hours; in the polar zones the days and nights are sometimes more than 24 hours long.

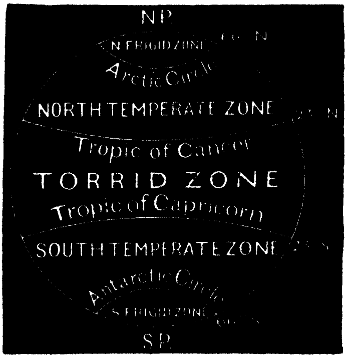

FIG. 262.—The sunshine zones.

It is clear that on this classification countries having very dissimilar climates are included in the same belt, since it takes no account either of many of the circumstances modifying temperature, or of the influence of prevailing winds.

Wind zones.—The suggestion by Prof. W. M. Davis that the great wind belts of the world be taken as the basis of a classification of climate has many points in its favour. Climate is dependent to a very great extent upon rainfall, which in its turn is controlled by the relative humidity and direction of the prevailing winds. According to this scheme, the "tropical" zone includes the equatorial belt of calms, and the regions over which the trade winds blow; the "temperate" zones similarly fall in the latitudes affected by the westerlies. Not only, however, are the boundaries of the wind belts somewhat indefinite at all times, but they shift according to the seasons.

Thus, countries on the polar margins of the trade-wind belts lie sometimes in the tropical and sometimes in the temperate zones, as thus defined. Again, a classification based entirely on prevailing winds would include in the temperate zones certain ill-defined regions falling within the Arctic and Antarctic circles, and having climates in no real sense temperate.

Temperate zones.—On the whole, perhaps the most generally satisfactory classification of climatic zones yet proposed is that due to Supan (Fig. 263). In it the **Hot Belt** is bounded by the two mean annual isotherms of 68° F., " a temperature which approximately coincides with the polar limit of the trade winds and with the polar limit of palms. The latter is considered by Griesbach to be the truest expression of a tropical climate. . . . The polar limits of the **temperate** zones are fixed by the isotherm of 50° F. for the warmest month. . . . Summer heat is more important for vegetation than winter cold, and where the warmest month has a temperature below 50° F. cereals and forest trees do not grow and man has to adjust himself to the conditions in a very special way ".* It has been pointed out that the great extremes of temperature and humidity, to which places in these zones are subject throughout the year, make the term " temperate " very unsuitable. They would be described more accurately as **intermediate** zones. Also the northern and southern caps are better called polar than frigid.

Types of Climate.—In each of the climatic zones thus defined there exists variety of climatic conditions, due largely to proximity or otherwise to the ocean, to the direction of prevailing winds, and to varying altitude of the land. It is therefore necessary to recognise in each zone a distinction between the marine or **oceanic** type and the **continental** type of climate ; with the intermediate variety known as the **littoral** (shore), and the extreme continental conditions of the **desert** climates. Among continental types **mountain** and **plateau** climates will also be included. In regard to temperature, the chief differences between these conditions have already been considered (Chapter XII). They may be conveniently summarised here.

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* " Climate ", by R. de C. Ward (Murray).

Marine or oceanic climate.—Water is warmed and cooled much more slowly than the land, and to a smaller extent for a given exposure to sunshine. Hence an oceanic climate is one with only a slight difference in summer and winter (Fig. 220) and in day and night temperatures. The copious evaporation keeps the air moist, favours cloudiness, and causes an abundant rainfall in the colder months.

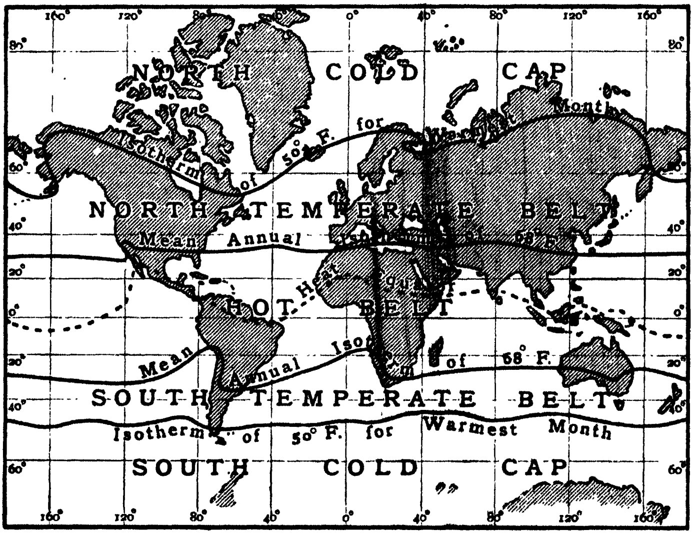

FIG. 263.—Supan's temperature zones.

The littoral or coast climate in general resembles the oceanic type, especially where the prevailing winds blow from the sea. Where the prevailing winds are in the opposite direction the coasts have naturally a climate approaching the continental type.

The continental climate.—The temperature of the land rises more quickly and to a greater extent than that of water in summer; conversely, it falls more quickly and to a greater extent in winter. Continental climates, therefore, show a large annual *range* of temperature, which is greater in general as the distance from the sea increases (Fig. 220). Further, the springs are warmer and the autumns cooler than in marine climates. The relative humidity and cloudiness of the atmosphere are less, and rainfall in general decreases, with distance from the sea ; although both the amount and frequency of rainfall depend considerably upon the prevailing winds and the elevation of the land.

Mountain and plateau climates differ from those of the lowlands in all parts of the world,

(1) in the lower pressure and temperature of the air ;

(2) in their freer exposure to solar light and heat, and at the same time, the more rapid cooling of their land surface, giving rise to greater *ranges* of temperature ;

(3) in their generally more abundant rainfall.

Mountain ranges often act as barriers, or *climatic divides*, separating regions of very different weather conditions. In this connection the fact that $\frac{9}{10}$ of the water vapour in the atmosphere is below 21,000 feet is significant. The desiccation of Tibet is ascribed to the effect of the Himalayas acting as a barrier to moisture-laden winds from the Indian Ocean.

The differences, in regard to temperature, of the principal types of climate, are clearly shown in the following table : *

Zone	Place	Type of Climate	Lat.	Mean Temp. of coldest month	Mean Temp. of warmest month	Range of Temperature
TROPICAL	Wady-Halfa	*Continental*	21° 53′ N.	61·3° F.	93·4° F.	32·1° F.
	Honolulu	*Marine*	21° 18′ N.	70°	77·5°	7·5°
SUB-TROPICAL	Bagdad	*Continental*	33° 19′ N.	50·9°	92·8°	41·9°
	Bermuda	*Marine*	32° 20′ N.	61·7°	80·1°	18·4°
TEMPERATE	Semipalatinsk	*Continental* (Lowland)	50° 24′ N.	0·5°	72°	71·5°
	Kiakhta (Mongolia)	*Continental* (Plateau)	50° 21′ N.	−15·9°	66·4°	82·3°
	Scilly Is.	*Marine* (W. Coast)	49° 55′ N.	45·7°	61·2°	15·5
	Saghalien Is.	*Marine* (E. Coast)	50° 50′ N.	−0·4°	62·2°	62·6°

The desert climate is an extreme type of the continental climate, showing an even greater contrast between the temperatures of day and night and of summer and winter. This accounts very largely (p. 299) for the extensive splitting and disintegration of rock masses, and the abundance of sand; and the high winds (which are as characteristic of deserts as they are of oceans) complete the erosion of the rocks by the scouring action of driven sand during sand storms.

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* Compiled from statistics given in Ward's " Climate " (Murray).

40. THE TROPICAL ZONE

1. The climates of the trade winds.—On an outline map of the world mark the great mountain chains and plateaux, and colour *blue* that side (called the windward side) of each on which the trade winds blow (*a*) from the sea, or (*b*) from a warmer to a colder region.

Are such winds likely to bring rainy or dry weather? Is the windward or the leeward (sheltered) side of a range of hills, exposed to a damp wind, likely to have the drier climate?

Colour *yellow* (*a*) the leeward sides of such hills, and (*b*) areas exposed to trade winds blowing from continents, or from colder to warmer regions.

For the present, leave uncoloured the southern and eastern coasts of Asia, the shores of the Gulf of Guinea, and equatorial Africa.

2. Monsoon climates.—Revise the account of the migration of the heat equator (p. 389) and of its effect upon the direction of the monsoons (p. 451). In which season of the year are the various monsoons rain-bringing and drying winds respectively? Why?

Colour appropriately (by alternate blue and yellow strokes) the regions affected by monsoons.

3. The belt of equatorial calms.—In the doldrums (p. 448) there are usually daily (*afternoon*) rains. Are the doldrums stationary, or do they shift with the migration of the heat equator? What countries do you suppose lie in the doldrums for part of the year and in a trade-wind zone for the rest? What tropical countries do you suppose have *in consequence* both dry and rainy seasons? Explain why. Are the various rainy seasons probable in our summer or in our winter?

Shade such countries as these on your map with black lines over the blue or yellow.

The tropical zone.—The climate of the " hot belt " of the earth—bounded by the mean annual isotherms of 68° F.—is, in its main features, remarkably uniform; and any variations of weather which do occur, appear at regular intervals—occasional tropical cyclones (p. 454) forming almost the only exception to the rule. The extent of the water surface in this zone greatly predominates over that of the land surface, so that the climate is on the whole " oceanic " in character (p. 476) with a typically small mean annual range (from 5° to 10° F.) of temperature (Fig. 220). Indeed, the differences between mean day and night temperatures are in most places—deserts excepted—larger than the mean annual range ; and seasons, in the ordinary sense of the word, do not exist. Variations in climatic conditions in the tropics are thus dependent upon the prevailing winds and rainfall.

The trade-wind belts.—Over the greater part of the tropical zone the **trade winds** blow with great regularity throughout the year. It has been learnt (p. 447) that these winds come from the north-east and south-east to regions of lower latitude, *i.e.* from relatively cooler to relatively warmer regions. So long as their course is over the sea or over low-lying land, therefore—and especially near their origin in the high pressure belts (Fig. 255)—the trade winds are dry. On the other hand, when they strike mountains they rise, are chilled by expansion, and the abundant moisture they contain is precipitated as rain. In general terms, then, it may be said that the **eastern slopes** of high lands in the trade-wind belts have a heavy rainfall and luxuriant tree growth ; low-lying land and the *western slopes* are relatively *dry*, and may even exhibit the " desert " type of climate. To these facts may be attributed the contrasts (Fig. 264) between the heavily watered east coasts and the much drier west coasts of Central America, the West Indies, the East Indies and Eastern Archipelago, Madagascar, Ceylon, etc. As for the continents of the zone, the coast of Guiana and south-eastern Brazil have a heavy rainfall, while the Pacific coast of South America (on the leeward side of the Andes) is a rainless desert from the equator to lat. 30° S., and another markedly arid region lies between the Brazilian Highlands and the Selvas of the Amazon.

Again, the rainfall map shows a striking contrast between the well-watered east coast of Australia and the **desert interior** from which the eastern highlands separate it ; and also between the south-eastern coast of Africa and the dry land to the leeward side of the mountain barrier. The cold ocean currents bathing the western coasts of South America and South Africa (Fig. 194) accentuate the inhospitality of these desert regions (Fig. 264). On such windward coasts and mountain slopes as those just described, where the rainfall is entirely derived from the trade winds, the " winter " is wetter than the " summer ", since the trades blow with greater force in winter.

The trade winds of northern Africa are not, in the first place, heavily laden with moisture, since they have not recently blown

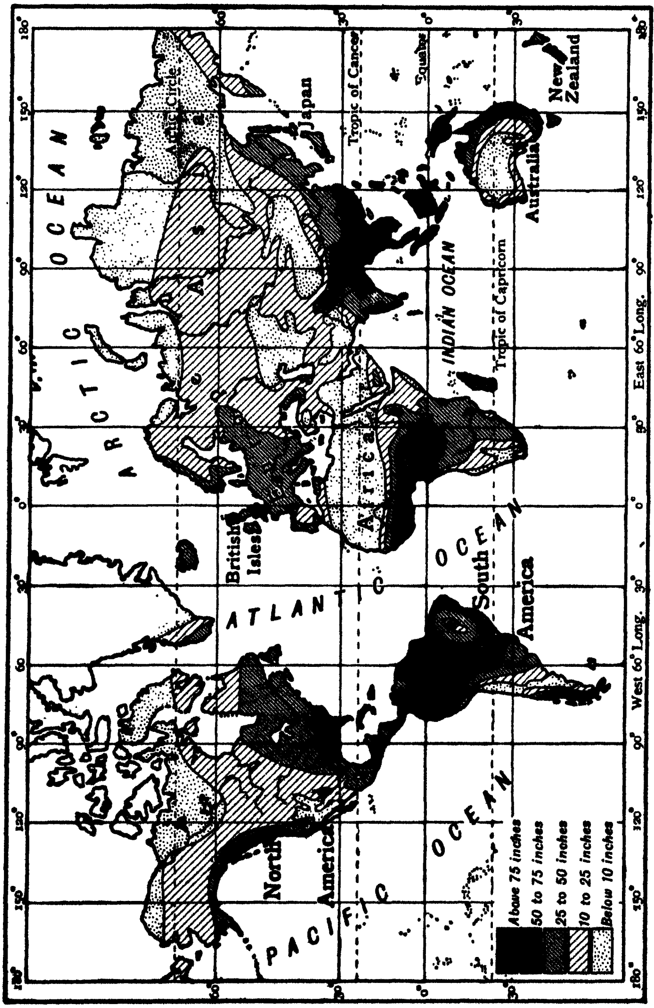


FIG. 264.—Rainfall map of the world.

over the ocean; and, secondly, since their direction is from higher to lower (*i.e.* from cooler to warmer) latitudes over flat country, their relative humidity is becoming increasingly less. As a consequence, the greater part of northern Africa is occupied by the desert of Sahara, with the characters of climate already described on p. 477. The conditions in Arabia north of the twentieth parallel of latitude are very much the same as those of the Sahara, and have resulted similarly in the formation of a desert.

Rains and water-supply.—In " The Traverse across the Great Indian Desert " carried out between November 1930 and January 1931 by Major E. A. Glennie from Reti near Sukkur to Kolait near Bikanir, 212 miles (see " Survey of India, Geodetic Report ", vol. vii. p. 60, 1932) they found that the rains had failed in the previous summer and all the *tobas* were dry (Fig. 266). At times the water for the party—56 men and 73 camels—had to be fetched from nine to nineteen miles away, while on the east of the desert the villagers store rain-water in covered pits lined with *kankar* lime mortar, and the water keeps sweet and clean. In many places there are only nomadic encampments with shelters, but there are plenty of cattle, large flocks of sheep and, in the dune area, poultry. Except for the cattle they seem to be almost independent of water in the cold

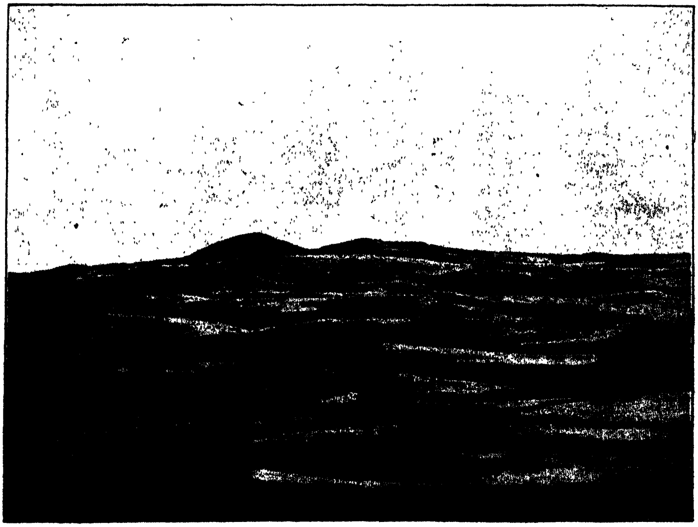


FIG. 265.—A view in the Sind Desert. (" Survey of India ", 1900-1.)

weather. The cattle go daily unattended eight or more miles to the wells where men are on duty to water them. Wolves are common in the central part of the desert, and gazelle and great bustard common everywhere. There were some partridge, but sand grouse were noticeably absent. The maximum day temperature varied between 70° and 80° F., while at night it usually dropped to 35° F. and on many occasions there was hard frost. There was very little wind, and visibility was excellent throughout, with no dust haze and remarkably little radiation.

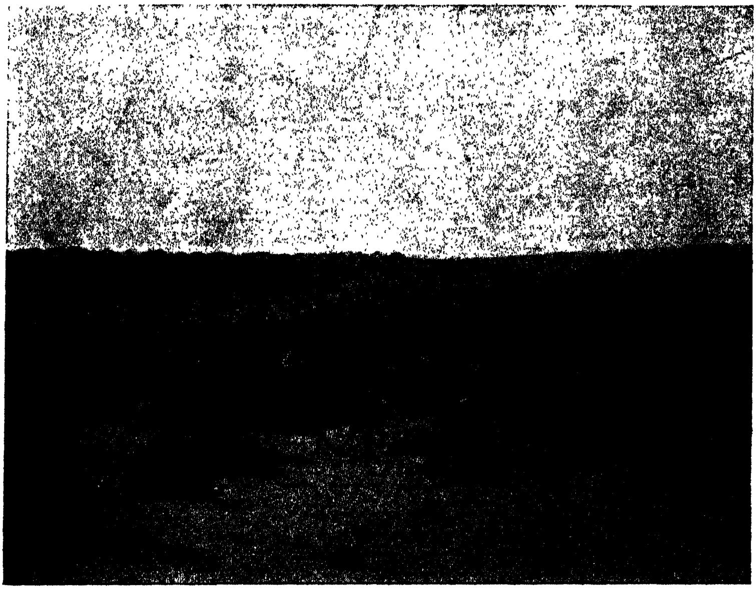


FIG. 266.—" The Traverse across the Great Indian Desert " by Major E. A. Glennie (" Survey of India, Geodetic Report," vol. vii. p. 60, 1932).

In contrast with the Great Indian Desert traverse (Fig. 267), the experiences of the party under Major G. H. Osmaston in the Assam-Burma Triangulation are of interest (see " Survey of India, Geodetic Report for 1935," p. 10, 1936). The triangulation was carried through unadministered territory inhabited by warlike Naga tribes so that an armed escort was necessary. No supplies could be counted on and coolies were the only form of transport on the steep forest-covered hills. Perimeter camps had to be built and no local men were allowed inside. The Patkai watershed pass is 6257 feet above sea-level. Several points on the Patkai ridge exceed 8000 feet and peak 9130 feet is the highest point. The Hukawng Valley proper is actually the basin of the Chindwin and must once have been a fine lake—even now the area is flooded during the rains, *i.e.* from June to October. Clouds were frequent and snow and wind made things very trying in January and February. Observations were taken at night to lamps on stations which were manned. The observer "called up" the stations with an electric torch after sunset. Heliographs were useless on the many cloudy days at this the supposed best time of the year in most parts of India.

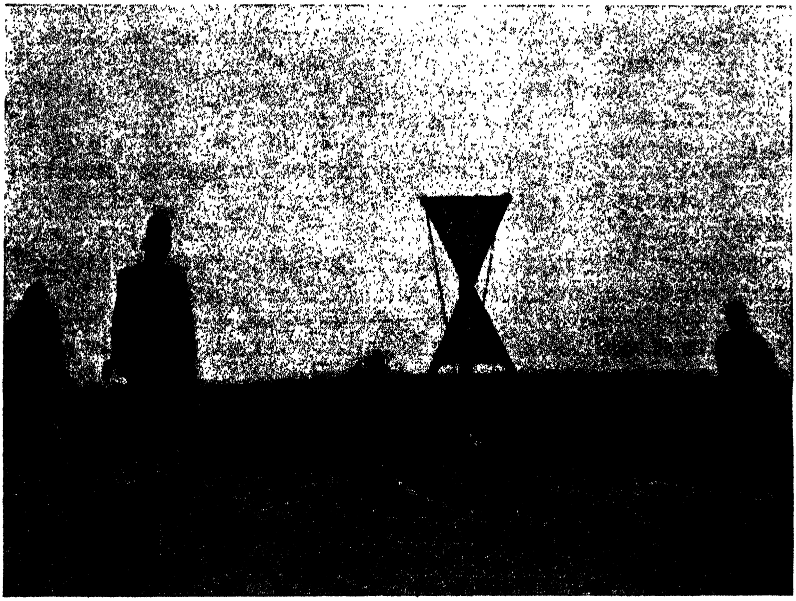


FIG. 267.—A trigonometrical station in the "Traverse across in the Great Indian Desert" by Major E. A. Glennie in 1930-31. (See Fig. 266.)

The equatorial belt.—It has been learnt (p. 448) that the **doldrums** are regions of calms between the north-east and south-east trades.

In the doldrums, the moisture which is evaporated during the hottest parts of the day is carried rapidly upwards, cooled by expansion, and condensed, so that daily rains fall in the afternoons and evenings. Since, however, the " belt of daily rains " follows the migration of the heat equator, it shifts a little to the north in our summer and a little to the south in our winter. It follows that places which lie in the doldrums and have daily rains, at one time of the year, may be in the trade-wind belt and have little or no rain at another. The resulting division of the year into **dry and rainy seasons** is naturally most marked near the extreme north and south limits of the annual migration of the doldrums, but in some regions—*e.g.* to the east of the Andes—it is not well marked. The wet season is naturally most prolonged nearest the equator ; and in parts of Central Africa and in the basin of the Amazon, for example, abundant rain falls at all seasons of the year, favouring the growth of dense forests.

Monsoon regions.—It has been explained in Chapter XIV that monsoon winds (which change with the season) are, like the alternating land and sea breezes of night and day, due to the unequal warming of land and sea, and blow, in general, from cooler to warmer regions. For this reason monsoons are drying winds unless they are cooled by local circumstances, as when they encounter high mountains ; in that case they bring heavy rain. Such is the case during the south-west monsoon, when it blows across the Arabian Sea and encounters the Western Ghats. Similarly, the rainfall on the southern slopes of the eastern Himalayas in the path of the monsoon from the Bay of Bengal is heavier than that of the central Himalaya, while the rainfall of Cherrapunji, on the southern edge of the Assam (Shillong) plateau and nearer the Bay of Bengal, is the heaviest known (464 in.).

The exceptional rainfall at Cherrapunji during the south-west monsoon is partly due to the physical configuration of the hills in that vicinity (see Fig. 26).

" It stands on a little plateau of thick bedded sandstones bounded on two sides by precipices of 2000 feet sheer descent, which close in gorges, debouching southwards on to the plains. The south-west wind blows up these as well as the southern face of the general scarp ; and having reached the heads of the gorges, ascends vertically. Thus Cherrapunji is surrounded, or nearly so, by vertically ascending currents of saturated air ; the dynamic cooling of which is the cause of the enormous precipitation which has made this place famous." (H. F. Blanford.)

The south-western monsoon of the summer (May to September) is sufficiently strong to overcome the north-east trades between lat. 10° N. and the Tropic of Cancer, or slightly beyond this, from East Africa to China. Wherever these winds are forced upward by the high lands of southern Asia and the East Indies, they similarly cause rain. In the northern winter, on the other hand, the monsoon winds of the same regions blow from the north, and reach northern Australia and the neighbouring islands as north-westerly rainy winds.

Southern Asia and the East Indies furnish the most conspicuous illustrations of climatic control by monsoons, but other examples are to be found in the Gulf of Guinea, and even in Spain.

41. THE TEMPERATE ZONES

1. The influence of winds upon rainfall.—To what extent do the " temperate " zones in Supan's classification correspond with the areas over which the westerlies blow? Do these winds come, in general, from warmer to cooler regions, or the reverse? Are they, as a consequence of this, likely to bring rainy or dry weather to (*a*) windward, (*b*) leeward coasts?

On your outline map mark in blue the coasts and slopes likely to be rainy, and in yellow those likely to be dry, on this account.

2. Annual range of temperature.—Examine Fig. 220. What evidence does it give that the north " temperate " zone is inappropriately named? Can you trace any connection between extent of temperature range and the character of the prevailing winds? Compare in this respect British Columbia, Labrador, England, and Kamchatka. Do ocean currents affect the facts materially?

Find out from Figs. 218 and 219 whether the summers are cooler in the north or in the south temperate zone.

3. Sub-tropical belts.—Bearing in mind the shifting of the trade-wind zone with the seasons, on what west coasts would you expect *dry summers and mild rainy winters*? What rainfall conditions would you expect in the Mediterranean region? Why? In what sense could California be expected to have the **Mediterranean type of climate?** Mention places in the southern hemisphere which seem likely to have a similar climate. Why cannot the Mediterranean type of climate be expected in Florida, in Japan, and on the east coasts of South Africa and Australia?

How would you expect the seasonal distribution of rainfall to differ in western Europe from the Mediterranean? What effect has this on the directions of winter and summer isotherms (p. 389)?

4. The climate of the British Isles.—What are the prevailing winds of the British Isles?

(*a*) *Rainfall.*—Examine Fig. 273 side by side with an orographical map of the British Isles. What and where is the greatest mean annual rainfall shown? What and where is the least? Which are the wettest and which the driest counties? Have hilly or flat districts a greater rainfall? Mention ten pairs of towns, on opposite sides of high land, which have marked differences in rainfall. Is the rainfall greater generally on the west, or on the east, side of hills and mountains? Is this the windward or the leeward side? Can you find any exceptions?

(*b*) *Temperature.*—Revise the exercises (4, p. 385) on the distribution of temperatures in the British Isles.

The temperate zones.—The so-called temperate zones—as defined by temperature—are included in each hemisphere between the mean annual isotherm of 68° F. and the isotherm of 50° F. for the warmest month. According to Supan's classification of climatic zones India, except the Himalayas, lies outside the north temperate zone. These zones comprise, broadly, the areas over which the westerlies (p. 447) blow. It will be remembered that these winds blow in general from lower to higher latitudes; they are therefore cooling continuously, and tend to cause mild rainy weather on the eastern shores of the oceans.

The oceanic type.—Even low-lying lands situated on the west coasts of continents are cool enough in winter to cause some condensation from the moist westerlies, and on the windward side of high lands in their path rain falls frequently at all seasons of the year, with a maximum in winter.

The continental type.—Having precipitated their moisture on any high lands they have encountered, the winds continue their journey to the east and north-east in a relatively dry condition, and as a consequence the central and eastern regions of the Americas and Asia within the zones show, on the whole, typical "continental" climates, with **deserts** in places. The semi-arid condition of the Great Basin of North America, between the Sierra Nevada and the Cascade Mountains to the west and the Rocky Mountains to the east, is a well-known example of such deserts; and the Shingle Desert of

Patagonia (Fig. 269) furnishes another. Over the continents in general, the maximum rainfall is in summer; it is due chiefly to monsoons and cyclones.

The effect of south-westerly winds blowing from the ocean is well illustrated by the contrast between the oceanic climates of British Columbia and the British Isles, and the continental climates of Labrador and Kamchatka, all near the ocean and in the same latitudes (50°–60° N.). In these examples, however, the modifying influence of the surface currents in the Pacific and the Atlantic (Chap. XI) must be borne in mind.

The north temperate zone.—The westerly winds, which are thus dominant over the temperate zones, are, however, much less constant in force and direction than the trades, largely because of the disturbing effects of local changes in temperature and pressure. This is especially the case in the northern hemisphere. On the large scale such changes may produce *monsoon* effects, as on the east coast of Asia, where the direction of the winds is completely reversed from summer to winter (p. 451); on a smaller scale they give rise to systems of low and high pressures—*cyclones and anti-cyclones*—which determine the weather throughout a great part of the year. The extreme changeableness of the weather of the temperate zones—which forms one of the points of contrast with the tropical zone—is to be attributed largely to cyclones and anti-cyclones. Though immensely inferior in severity to tropical storms, British cyclones succeed each other so rapidly—especially in winter—that as "climatic controls" they far outweigh tropical storms in importance.

In both the north and the south temperate zones, climate is a matter of **seasonal variations of temperature** rather than of rainfall. It is, indeed, the great difference between winter and summer temperatures found in the north "temperate" zone (most notably in eastern Siberia) which furnishes the chief objection to such a misnomer as the word temperate. Within the "continental" regions of this zone the summer is in places quite as hot as in the tropics, while the winter is frigid in its severity. The mean daily range of temperature is less than the mean annual range—a state of things exactly opposite to what obtains in the tropical zone. Further, in the north temperate zone there is a greater difference between the marine and continental types of climate than is found in the tropics.

The south temperate zone.—Owing largely to the great preponderance of water over land in the southern hemisphere, the south temperate zone as a whole exhibits much smaller annual variations in temperature than the northern, and may be described as truly temperate. As an examination of Figs. 218 and 219 shows, the summers are on the whole cooler in this zone than in corresponding northern latitudes, and for that reason agriculture cannot be carried on so successfully. In this zone, moreover, the westerlies are but little affected by cyclonic and anti-cyclonic whirls, and the " brave west winds " blow with great steadiness and strength.

The sub-tropical belts.—On the *western* coasts of the continents, in latitudes between about 28° and 40° in both hemispheres, the climate is controlled alternately by the trade winds (in summer) and the westerlies (in winter). They are characterised, therefore, by hot, dry summers, and by mild winters in which moderate (Fig. 268) and irregular rains alternate with the prevailing sunny weather. The mean temperature of the coldest month rarely reaches freezing point. This type of climate is often known as the **Mediterranean climate,** because it extends over a greater area in southern Europe, northern Africa, and eastward to Persia, than in any other part of the world. California, northern Chile, and the south-western coasts of Africa and Australia are favoured by similar climatic conditions.

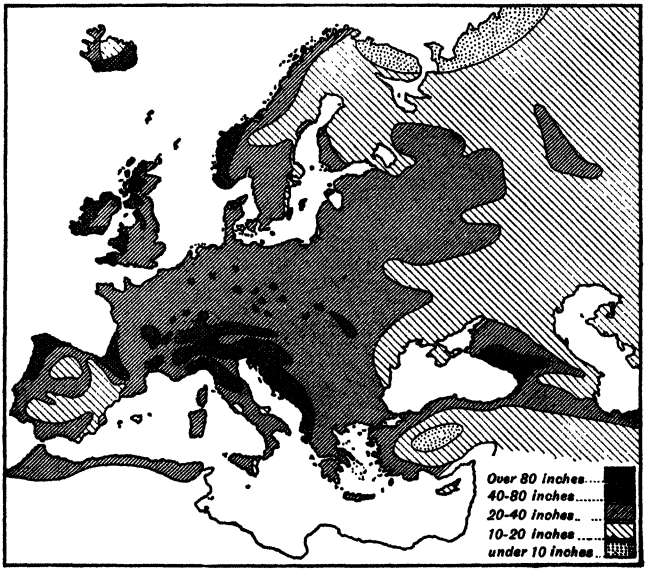
The Mediterranean region has several minor advantages—due to local conditions—over these countries. The Mediterranean Sea causes the temperature to be more equable ; the ranges of mountains to the north protect it from cold winds (the Sierra Nevada, however, has a like influence in favour of the Californian climate), and their slopes give to its northern limits the benefits of a sunny southern exposure ; while the dry north-east trade winds of summer are strengthened by the position of the desert of Sahara, which is a region of low barometric pressure. Further, the prevailing winds from the ocean in winter are warmer than those blowing over the sub-tropical western coasts in other parts of the world.

The *eastern* coasts of the continents in the same latitudes, however, have often summer rains from the monsoons, which interfere with the normal course of the sub-tropical trade winds ; while in the interiors there is a tendency to spring and autumn rains.

The changes in climate from the equator polewards are shown admirably in South America (Fig. 269), where the characters of the oceanic and continental types of the various zones succeed each other with great regularity.

Climate of the British Isles.—The Meteorological Office, London, has published a summary of observations of barometric height, temperature, rainfall and bright sunshine, made during a period of a quarter of a century at a large number of stations in different parts of the British Isles. The following are a few of the facts brought out by the comparison of results :

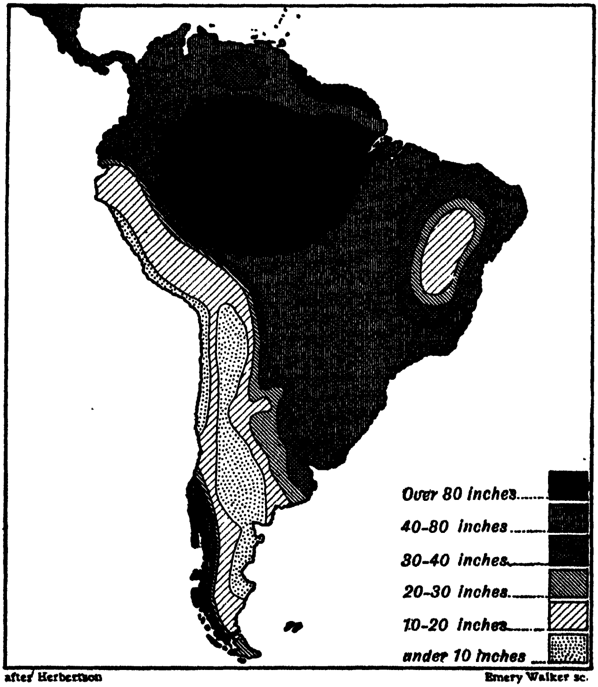
The average readings of the **barometer** are much lower over the northern and north-western portion of the kingdom than in the south and south-east during all the winter months, and this explains the great predominance of westerly and south-westerly winds which blow over us from the Atlantic (Figs. 271 and 272). In the summer the barometer readings are much more uniform over the whole country, and the winds are, consequently, of less strength and more variable in direction. The lowest **mean temperature** occurs nearly always in January over the whole country, and it ranges from 37° F. in Scotland and the English midlands to 45° F. at Scilly, and 44° F. at Valentia. The highest mean temperature occurs in July and August, these two months being about equally warm in all parts of the country. The mean at the Scottish stations is 56° F., in Ireland 59° F., and in England 61° F. London and Jersey enjoy the highest summer mean temperature, the average being 63° F. The values of



Emery Walker sc.

FIG. 268.—Rainfall map of Europe.

absolute minimum temperature show that in December, January and February, the temperature occasionally falls below 10° F. in different parts of the kingdom; but readings below 0° F. are extremely uncommon. Frost may occur in any part of the country in April, and it sometimes occurs in May, except at the extreme western stations. Frost occurs in many parts of Great Britain in September, and is of frequent occurrence in October and November, readings falling below 20° F. in the latter month. As to **rainfall**, after Seathwaite and its neighbourhood, the heaviest rainfall occurs at Glencarron, where the total fall for the year is 86 in., and at Fort-William, where it is 77 in. One of the lowest annual rainfalls is 23·3 in. at Cambridge. In London, the total for the year is 24·8 in. The average annual rainfall for the British Isles is about 39½ in. The driest part of the year is March in the eastern and midland districts of England; April



after Herbertson

Emery Walker sc.

Fig. 269.—Rainfall map of South America.

generally in Scotland, Ireland and the west of England; while in the south-west of England it is as late as May. The heaviest rainfall in England is mostly in October (Fig. 270); but in Scotland and Ireland it is far more irregular, occurring sometimes in winter and sometimes in summer.

Seasonal variation in the English climate.—In an interesting paper,[*] Mr. W. Marriott gave the following results obtained by averaging the monthly climatic records of the thirty years 1881-1910.

January is the coldest month; after which the **temperature** rises month by month until July. In August it is slightly lower, after which the temperature falls again—the fall from September to October being very abrupt.

The **rainfall** curve shows that April and May are the driest months, after which the rainfall increases to August (which is really a wet month), then falls considerably in September, but the maximum occurs in October; November and December are also wet months. The month with the least number of rain days[†] is June, with 12 on the average; May and September are the next driest months. October and December are the months with the greatest number of rain days. September, in fact, comes out in all the elements as a fine month.

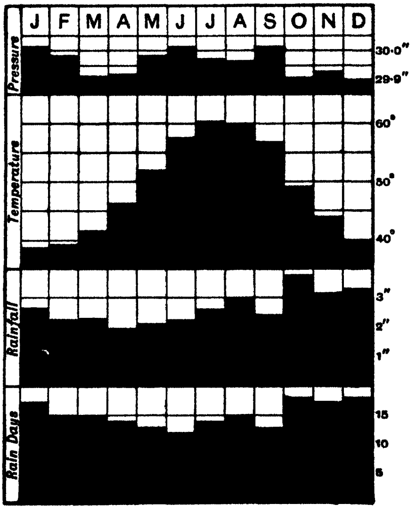


FIG. 270.—Monthly averages of climatic factors in England from 1881 to 1910 (Marriott).

The **atmospheric pressure** is high in January and February, low in March and April, high from May to September, and low from October to December. The fall from September to October, and the rise from December to January, are very pronounced.

The prevalence of the **winds** from each point of the compass is shown in the wind-roses in Figs. 271 and 272. The winds from the south-west and west are very pronounced in most months, except in the spring, when there is a large percentage of north-easterly winds. This is brought out very clearly by combining the values for south-westerly and westerly winds as representing the " south-westerly type ", and also those for north-easterly and easterly winds as representing the " north-easterly type " of winds. In July and August the winds are most distinctly of a westerly type.

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[*] Marriott: "Variations in the English Climate, 1881-1910." (*Q.J. Roy. Met. Soc.*, July 1911.)

[†] A "rain day" is taken to be a day on which 0·01 inch has been recorded.

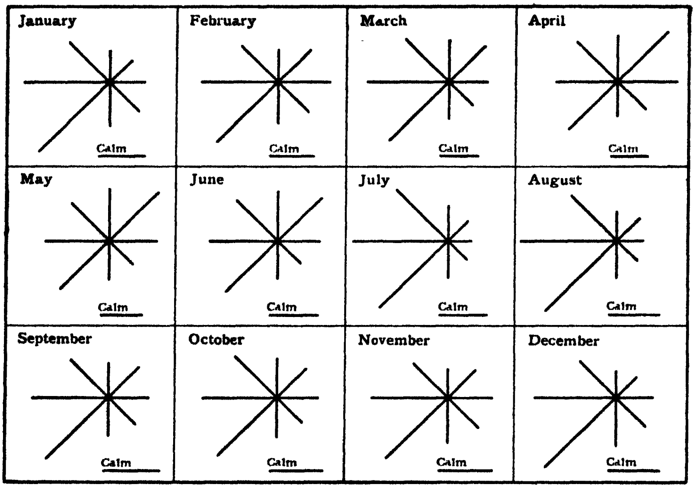


FIG. 271.—Average monthly proportions of wind-directions in England from 1881 to 1910 (Marriott).

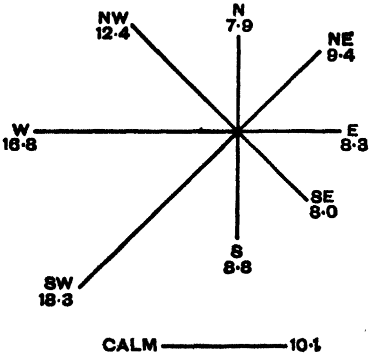
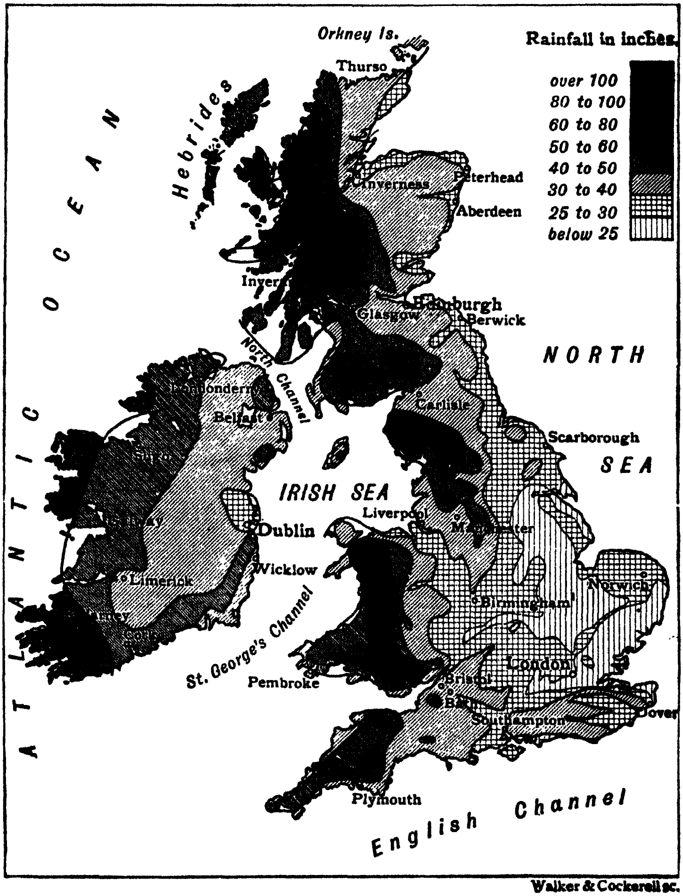


FIG. 272.—Average annual percentage of wind-directions in England from 1881 to 1910 (Marriott).

The percentage of calms shows that March, April and May—especially April—are the windiest months; that is, the months in which the least number of calms is reported at 9 a.m. and 9 p.m. The calmest months are September, October and November—especially September.

The most **cloudy months** are November to February, and the least cloudy months May, June and September. The winter months have also the greatest **relative humidity**, while the spring and summer months, April to August, have the least relative humidity, May being the driest month of all.



Walker & Cockerell sc.

FIG. 273.—Rainfall map of the British Isles, showing mean annual precipitation.

Rainfall in England.—The **distribution** of the rainfall in this country (Fig. 273) is explained easily. Since the mountains near the west of England form three groups, *viz.* those of (1) Westmoreland and Cumberland; (2) Wales; (3) Cornwall and Devon; and since in addition to this the prevailing winds blow from the south-west, the rainfall in these districts will be much higher than elsewhere. The annual rainfall in parts of Cumberland is above 75 inches, while at Seathwaite it averages 135 inches, and at the Stye Head, a mile away, it is about 170 inches, which is the greatest recorded annual rainfall in Europe. In the second of the groups of mountains mentioned, the greatest rainfall occurs in the neighbourhood of Blaenae Festiniog, where the annual rainfall reaches upwards of 75 inches. This amount is also recorded in the third mountainous district, in the locality of Dartmoor. Throughout the Lake country the rainfall is over 50 inches in the year, and the same is true of all the mountainous parts of Wales and the higher portions of Devon and Cornwall. If we draw a line from the middle of the Cheviot Hills almost due north and south to Birmingham, and another from this place to Liverpool, we shall have included an area in the north-west where the rainfall varies between 30 and 40 inches per year. The same numbers apply to that part of the southern counties south of the Downs, and to the parts of Gloucestershire round the Cotswold Hills. The central parts of England as far east as Oxford possess a rainfall of from 25 to 30 inches, while that of the eastern counties as far west as this university town is below 25 inches in the year.

42. THE POLAR ZONES

The limits of the zones.—As limited by the Arctic and Antarctic circles, each polar zone has an area of about $\frac{2}{25}$th of that of the hemisphere. Defined by the isotherm of 52° F. for the warmest month—the polar limit of forest trees and cereals—the margin of the north polar zone departs considerably, in places, from parallelism with the Arctic circle, in accordance with the influence of the great land masses upon the distribution of temperature. On the other hand, the corresponding isotherm of the southern hemisphere, freed from the disturbing effects of continents, is roughly parallel to the lines of latitude.

The temperatures of the zones.—In spite of the great amount of solar heat received by the polar zones at their respective summer solstices, their mean annual temperatures are the lowest known. This is a result, chiefly, of the large amount of heat which, without raising the temperature, is required to melt the ice and snow (p. 403); the extent of the winter—when the sun is below the horizon for periods varying, with the latitude, from 24 hours to six months at a time—further neutralises the effects of the summer. On the other hand, the lowest air temperatures yet recorded for polar zones * fail to reach the minimum (– 90° F.) for eastern Siberia just outside the boundary line.

South of lat. 70° S. the Antarctic regions appear † to be colder than the Arctic, and over the south polar zone generally the summers are colder than in the north. This accounts for the extreme dearth of vegetation in the Antarctic as compared with the Arctic regions.

As in the adjoining parts of the temperate zones, it is found that the autumns are warmer than the springs. The " lagging " of spring is, again, to be explained by the absorption of so much heat by the melting ice and snow. The process is naturally more retarded where the surface is level and the water produced by melting is unable to drain away. Such places remain deserts. Where, however, the surface slopes to allow of drainage, and the soil beneath can be warmed, the brief summer often induces the growth, in the Arctic regions, of a veritable garden of flowers. The temperature is distinctly lower in eastern than in western Greenland.

Winds and rainfall.—Owing to the absence of large irregular land masses in the Antarctic, the winds there blow with great regularity from the east and south-east—apparently from an enormous high-pressure system, or anti-cyclone, round the pole. This is surrounded by a low-pressure girdle at about the Antarctic circle. In the Arctic regions the winds are much less regular.

The polar zones are, naturally, more or less invaded at their margins by the westerly winds of lower latitudes, which are associated with cyclonic systems. At the margins, therefore, the rainfall is under cyclonic control. Nearer the poles, however, there is a relative absence of cyclones and a scarcity of rainfall, especially in winter. The air is, indeed, so cold as to be capable of holding but little water vapour. The slightly warmer winds of summer take up the increased amount of water evaporated then, but it is soon precipitated, usually as snow.

The severity of the climate of Greenland, as well as of Victoria Land in the south zone, is somewhat mitigated by irregular winds blowing *down* the mountains and becoming warmed by the increased pressure. The " Föhn " and the " Chinook "—the warm, dry winds respectively descending the northern slopes of the Alps and the eastern slopes of the Rockies—are of similar nature.

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* The lowest recorded by Scott was – 77° F. in lat. 82° S.

† Hann.

EXERCISES ON CHAPTER XV

1. In what parts of the world is the difference of temperature between the hottest and coldest months (*a*) greatest, and (*b*) least? How do you account for the facts?

2. State some of the circumstances that determine the climate of a place, giving as examples Assam, the Punjab and Ceylon.

3. What are the chief differences between the climate of a place in the tropics, such as Hyderabad (Deccan), and that of one in the British Isles? Account as far as you can for the differences you mention.

4. What is meant by a " Mediterranean climate "? Where is such a climate found? Account fully for it.

5. Compare the climate of the west coast of Burma with that of the east coast of Madras ; and the climate of Simla with that of Delhi. In each case explain the difference.

6. Compare the winter and summer climate (*a*) of south-western Asia with those of the south-east side of Asia, and (*b*) of eastern Europe with those of western Europe. What explanation do you give of the differences?

7. Robinson Crusoe classifies the climate of his island so—

Middle of February to middle of April = Rainy season ;
,, April ,, ,, August = Dry season ;
,, August ,, ,, October = Rainy season ;
,, October ,, ,, February = Dry season ;

and adds that, for his barley and rice, he has two seedtimes and two harvests every year. From the information here given show that Crusoe is right in saying that the island cannot be a part of Europe.

8. In the Indian peninsula winds from the W. and S.W., as a rule, are warm and generally rain-bearing, and winds from the E. and N.E. are cold and generally dry, except on the Coromandel coast of Madras. Account for these differences. Compare the characteristics of the prevailing winds of the British Isles with those of the United States of America and India.

9. State and account for the chief characteristics of a land climate as regards variation of temperature, amount of rainfall, and distribution of wet and dry seasons. Give examples.

10. Describe and account for the differences in the climate on the east and west coasts of *one* of the following regions : (*a*) northern Scotland ; (*b*) southern India ; (*c*) the southern part of South America.

11. Mention the climatic zones of the northern hemisphere, giving a description of their limits and characteristics.

12. Write an account of (*a*) the position and extent, (*b*) the climate, (*c*) the physical features of the desert region of Australia.

13. Describe and explain the distribution of rainfall in South America.

14. Describe, broadly, the relief of central Asia, and point out any peculiarities of the climate immediately resulting from it.

15. " There are three main climatic regions in Europe—the Atlantic, the Continental, the Mediterranean." Show how and why these differ from one another (i) in seasonal distribution of rain, (ii) in conditions of temperature.

16. State as precisely as possible which parts of the world have very great rainfall. Account for the facts.

17. It is found that, on the whole, the greatest annual rainfall occurs near the equator, and the amount is less the higher the latitude.

How do you account for this? Mention an important region which forms an important exception to this rule, stating how and why it deviates from the rule.

18. Compared with central England, the climate of Cornwall is noted for (*a*) cool summers and mild winters, and (*b*) abundant rainfall. How do you account for these facts?

19. Compare the climates of western and eastern India (say of Baluchistan and Assam) in summer and in winter, and give reasons for any differences.

20. Give some account of the climate of the British Isles, pointing out the effects of the physical configuration of the country, the prevailing winds, and the surrounding waters.

The mean annual rainfall at Harwich is about 23 inches and at Belmullet, on the west coast of Mayo, about 50 inches. How do you account for this difference?

21. Durban (30° S. lat.) and Suez (30° N. lat.) are in nearly the same latitude, on opposite sides of the equator. Explain the difference in the climates of these places.

22. Massawa, Marmagao, Moulmein and Manilla are nearly in the same latitude. What are the differences of climate between these places, and how do you account for these differences?

23. " The winter climate of the British Isles is more temperate than is justified by its latitude." Enumerate briefly the causes of this. How does this anomalous climate affect the products of these islands and the industries of the people? What other insular areas with approximately the same latitude lack this anomalous climate?

24. Mention some district near a large ocean where the rainfall is slight, and another far from the coast where the fall is heavy. Account, in each case, for these conditions.

25. What are the different factors that cause two places on the same latitude to vary in climate? Give an illustration for each different condition mentioned.

26. It is usual to treat the portions of Europe and Africa which border upon the Mediterranean Sea as a distinct geographical region. What characteristics justify this treatment?

27. State which side of Great Britain has the higher and which the lower rainfall. Explain the difference and point out any influence which it has on the agricultural or manufacturing industries of the country.

28. Explain exactly what is meant by the statement, " The average rainfall of the Thames basin is 26 inches." What are the chief causes that determine the distribution of rain ?

29. Describe shortly the distribution of rainfall in Australia. What are the three main winds from which the rainfall is derived?

30. In what parts of the world do we find autumn and winter rains prevailing? Give what explanation you can.

31. The centre of Australia, Tibet, the Sahara, and the plateau of the western United States have very little rainfall. Can you account for this by any general principle?

32. Give a full account of the distribution of rainfall in Africa, and show how it affects vegetation.

33. Which are the least rainy parts of India and why?

34. What is approximately the average annual rainfall in the district in which you are examined? Explain the causes which affect the rainfall in that district.

35. To what extent is it true that the average amount of annual rainfall is greatest at the equator and diminishes towards the poles? Account for the facts.

36. State, with reasons, which of the following towns are warmest in January :—(*a*) Melbourne or Brisbane, (*b*) Lisbon or Madrid. State also, with reasons, which of the following have the greatest annual rainfall :—(*a*) Bergen or Stockholm, (*b*) Constantinople or Cairo. State, with regard to any *two* of the following districts, whether they receive the bulk of their rainfall in the cold season, or the hot season, or pretty equally all the year round :—Italy, the Upper Nile basin, Ireland, the plain of the Ganges, southern Russia.

37. Discuss briefly the causes of differences of climate in different parts of the earth, showing especially what conditions have produced desert areas now existing.

38. The chief characteristic of the climate of the Mediterranean region is that most of the rain falls in the winter months. Explain fully how this occurs.

39. In India persistent winds blow for four or five months in one direction followed by persistent winds for nearly six months in a roughly contrary direction. What effects have these winds upon the country? Describe the climate usually possessed by a country which is the middle of a continent and a long way from the sea.

40. Contrast the climate of the Scilly Isles with that of the Orkney Islands, (*a*) in summer, (*b*) in winter.

41. " In the trade-wind belt, dry regions are found towards the western sides of the land masses, while in higher latitudes they occur towards the east." Explain the reasons for these facts, and give examples in illustration of them.

42. The south-west of Cape Colony is said to have a Mediterranean type of climate. Explain fully what this means and how it is brought about.

43. Mention the parts of Abyssinia (Ethiopia) which have the lowest and heaviest rainfall, and give the reasons for this distribution. Is this country subject to dry and wet monsoon periods ?

44. Contrast the climate of the Abyssinian plateau with that of French Somaliland, and account for the differences.

45. In what season of the year would you expect rain to fall in the different parts of southern Arabia? Account as fully as you can for any facts that you mention.

46. Compare the climate of New Zealand with that of the British Isles, and explain the causes of such similarities as you mention.

47. A farmer from the Punjab wishes to settle in some " oversea " portion of the Empire. He is anxious to live as nearly as possible in the same kind of climate as at home. To which parts of East or South Africa, and Australia would you recommend him to look? Give reasons for thinking that the places you name have a similar climate.

48. On the blank map of India show (*a*) the important limestone and chalk districts, (*b*) three isotherms for January and three for July, (*c*) the areas with more than 60 inches of rain per annum, (*d*) the position of the Rann of Cutch, the Satpura uplands, the Swatch of No Ground, Chilka lake, Minicoy, the Pamban pass, Manora point, Barren Island, the Sandheads.

CHAPTER XVI

THE GEOGRAPHICAL DISTRIBUTION OF PLANTS

43. CIRCUMSTANCES AFFECTING DISTRIBUTION

1. The loss of water vapour by leaves.—(*a*) Cut off a leafy twig from a teak, sal, peepul, sycamore (Fig. 276), pipal, oak, or other " broad leaved " tree, and leave it exposed to sunlight for an hour or two; notice the change in the appearance of the leaves. If possible, weigh the twig before and after the experiment.

(*b*) Put a similar twig in the dark for the same length of time; again notice the leaves. Is the difference in result due to lack of light or lack of heat? To test this, keep, if possible, a similar twig in the dark in a fairly warm place. Do the leaves wither as much as in (*a*)?

(*c*) Smear with vaseline the *lower* surfaces of some of the leaves of such twigs and again expose to sunlight. Do the smeared leaves remain fresh longer than the others?

(*d*) Make observations similar to the above on leaves and branches of herbaceous (soft-stemmed) plants from the garden or field.

(*e*) Arrange herbaceous plants with their roots (washed free from earth) dipping in water, and also leafy twigs of broad-leaved trees with their ends (freshly cut whilst under water) in water, and expose to sunlight. The leaves remain fresh; why? Which part of a plant usually takes up its water supply? What was the cause of the withering of the leaves in the foregoing experiments?

2. The effect of chilling the roots.—Repeat Expt. 1 (*e*) above, but put ice in the water to keep the roots very cold. Do the leaves wither although the plant is well supplied with water? What, evidently, is the effect of cold on the power of water absorption by roots? Would it be to the plant's advantage to give off water freely by the leaves when the roots were chilled? Suggest a reason why most of our forest trees shed their leaves in winter. Suggest a reason why most of our herbaceous plants " die down " to the ground in winter, even though they may survive the winter by means of underground parts.

3. Evergreen plants.—What forest trees found in the Indian region are evergreen? What other Indian plants, growing in the open, retain their leaves in winter? Examine and experiment with their leaves, and describe the shape, texture, surface, etc., of any leaves which you find to give off water very slowly. Classify such plants into groups according as they grow wild in very dry or very cold situations.

4. Characteristic Indian vegetation. (*Outdoor work.*)—Take advantage of excursions, etc., particularly in your own tehsil or district, to acquire gradually a knowledge (*a*) of the extent of grassland, including rice, jowari and other fields ; and of the areas covered by (*b*) forest trees bearing leaves which are shed in winter, (*c*) evergreen trees, (*d*) low shrubby plants (heath, etc.), mosses, etc.

Indicate each by a distinctive colour-wash on a map.

Which of these are found on exposed, high land, on sheltered hill-sides, in well-watered valleys, and over well-watered plains respectively?

In each group try to learn the names of the commonest plants.

5. Influence of temperature.—What plants, grown in palm-houses, are unknown in the open in this country? Learn the usual temperature inside as many palm-houses as you have access to. Examine isotherm maps of the world to find which countries have such temperatures.

The relation of plant structure to habitat.—The most casual acquaintance with plants growing under natural conditions is sufficient to convince any one that certain forms of vegetation flourish most easily in marshy ground, others in dry soils, and still others in situations which are intermediate in character. Similarly, plants at home in sheltered situations are in many cases unable to live in places exposed to strong winds ; while others cannot endure the low temperatures associated with circumstances otherwise suitable. The conditions of moisture, temperature, soil, and the like under which any particular kind of plant habitually grows are said to constitute its **habitat.** Thus mountains, moorlands, and ditches form the respective habitats of the Scotch fir, heather and the common sedge in the British Isles.

A closer knowledge of the means by which plants are adapted to their environment reveals **the paramount importance of the water-supply** as a factor of the habitat. Indeed, the danger of becoming too dry is on the whole the greatest which plants in general have to face. Whenever green plants are exposed to light they are losing moisture in the form of water vapour, which is given off, for the most part, by the leaves in the process known as transpiration. So long as an abundance of water is forthcoming from the soil to replace this loss, free transpiration has no ill effects. It becomes highly dangerous, however, if for any reason the roots are unable to supply enough water to keep pace with it. Such a state of actual or physiological drought may arise from very varying circumstances.

Among the commonest are, first, the **lack of water in the soil.** This condition is found in deserts and in smaller local areas in all parts of the world. It naturally offers the greatest difficulties to plant life where high temperatures or dry winds join with bright sunlight in promoting transpiration.

Secondly, the fact that, when chilled, roots become, as it were, " numbed " and unable to absorb water easily, even from moist soil, must be noted. It is this difficulty, brought on by very *cold weather*, with which plants in our own and similar climates are compelled to cope in winter. Those which have no other means of limiting transpiration must resort to such extreme measures as the sacrifice of their leaves in the case of woody plants (trees and shrubs), or the death of all parts above the ground in the case of soft-stemmed (herbaceous) plants, if they are to survive the winter. Plants which shed all their leaves at definite seasons are described as *deciduous*.

A third source of difficulty is found by plants living in soils containing appreciable quantities of *salts or organic acids*, because these also interfere with the absorption of water by roots. The curious result is that plants growing in bogs containing decaying vegetation, or in salt marshes, need some means of checking transpiration, in order to escape water-starvation.

Plants which are adapted for life under such conditions of physical or physiological drought as are described above are called **xerophytes** or drought-plants. They are sometimes said to be " xerophilous " or drought-loving, though in many instances the conditions of their life are probably more to their disadvantage than their advantage. Since transpiration is essentially the work of leaves, it is by modifications of the leaves that xerophytic plants chiefly provide against drought. The leaves are succulent, fleshy, leathery, hairy, covered with wax, rolled up, needle-shaped (Fig. 278), very small, or even absent altogether, in different xerophytes, since each, or a combination, of these characters reduces the extent of transpiration.

At the other extreme is the condition of having **an abundance of moisture at all times,** under which plants live in soil of moderate temperature which is always able to afford a regular and adequate supply of water to the roots. In these circumstances, all serious interruptions of growth are avoided, and the plants are mainly *perennials*, that is, they live on from year to year. Among perennial plants, **trees** are the dominant type, so that well-watered countries in the tropical and temperate zones are naturally afforested.

In countries having a regularly **recurring dry season,** trees are scarcer, and their place is taken by herbaceous plants, chiefly *annuals*. Herbs are active only during the moist season, towards the end of which they produce seeds, or else tubers, bulbs, etc., capable of withstanding the coming drought. The plants then die down, but their seeds, bulbs, etc., survive, and pass in their turn through the same life-history when the necessary moisture is available. **Grasses** are, on the whole, the most successful of herbaceous plants, and they form the greater part of the vegetation of countries having this type of climate.

Plants characteristic of climates which show no extremes of wet and dry, or of hot and cold seasons are called **mesophytes.** In a general sense **British plants** fall in this group, although most of them need to adopt certain precautions against the cold—and consequent difficulty of absorbing water—in winter. The "broad-leaved" deciduous trees mostly belong to this group, but Indian plants, owing to the wide variations of climate and temperature, fall in the **Mesophytes** group as well as under the **Xerophytes,** referred to on page 502, and also under that of **Hydrophytes,** which are plants growing in abundance of water.

In general, the main groups of "plant communities" outlined above merge gradually into each other, as climates themselves merge gradually into each other.

Temperature and soil as factors in habitat.—It is well known that many plants which are abundant in the tropics cannot grow—except when provided with artificial heat—in temperate countries. Although the temperature of soil and air does operate directly to some extent in limiting the distribution of plants, its effect is chiefly indirect, and a result of the influence which temperature has upon the ease or otherwise with which the plants absorb or retain water. Similarly, certain plants grow far more abundantly in chalky soil than in clay, and *vice versa*, and there is a natural tendency to suppose that the *chemical* composition of the soil accounts for the difference between the characteristic plants. It is, however, the *physical* condition of the soil—dry, easily warmed and porous in the case of chalk, "heavy" and largely impervious to both air and water in the case of clay—which is chiefly responsible, by placing a smaller or greater amount of heat, water and air at the disposal of the roots.

Methods of dispersion.—For a description of the various means which plants adopt to scatter their seeds or get them scattered by the wind, by water, or by animals, a text-book of botany should be consulted. We are concerned here chiefly with the dispersion of plants, by seeds, or otherwise, from country to country. Besides the intentional introduction by mankind of useful plants, and accidentally of those undesirable plants called weeds, account must be taken of the action of winds in the gradual dispersion over continents, and from time to time across narrow seas, of plants producing light seeds; of the agency of birds in carrying seeds uninjured either in their digestive organs or attached by mud to their feet; of transportation by oceanic currents, icebergs, floating tree trunks, and other means.*

Obstacles to dispersion.—In spite of these and other methods by which plants may "spread" from country to country, it is common knowledge that plants do not by any means occur invariably in all habitats which are suitable for them. Similar conditions of climate and soil in different parts of the world often support a markedly different flora. The fact may be attributed to one of two causes: migration may have been prevented by barriers, or the plants may have reached a suitable habitat only to find it occupied already by species which they were unable to oust.

The principal **barriers** preventing unlimited colonisation are deserts, wide oceans and high mountain ranges. It is difficult to believe that seeds of flowering plants could be carried, except in the most improbable circumstances, across such barriers, by any means other than human agency; and none but comparatively recent migrations can be attributed to mankind. On the other hand the minute dust-like spores of many very simple plants may conceivably have attained a world-wide distribution by means of the wind alone.

Again, the intensity of **competition** may easily explain why a newcomer may fail to obtain a footing in a habitat quite suitable to its

* See Darwin's "Origin of Species", chap. xii.

In 1883 most, if not all, of the plant-life on the island of Krakatoa was destroyed by a volcanic eruption (p. 221). In 1906, 137 species of plants were collected in a few hours by a party of botanists on the island, who found trees 50 feet high as well as thick jungle.

needs. Only if it possessed some advantage over those already settled in the station, would it have any chance of beating them in the struggle for existence, since only the " fittest "—that is, those best able to take advantage of the favourable circumstances and to overcome the difficulties of the situation—can survive where every inch of room is keenly contested.

Discontinuous distribution.—On the assumption—which modern biologists feel quite justified in making—that the same species of plant or animal has not originated more than once in the history of the earth, it is clear that if the same species occurs on both sides of an impassable barrier, the species is of greater age than the barrier. Though now discontinuously, it must once have been continuously distributed.

Further, if any particular species occurs only at widely separated stations, although suitable habitats exist between these stations, it is highly probable that the species is an ancient one—formerly distributed continuously—which for some reason has become extinct over the greater part of its range, surviving here and there in isolated areas owing to freedom from competition or other favouring circumstances. Some of the results obtained by applying these principles are highly interesting.

The presence of Arctic species of saxifrage, etc., on the higher slopes or summits of mountains of the Swiss Alps and even on some mountains in Britain, while they are absent over all the intervening low-lying land, is usually explained by the fact that in the great Ice Age already referred to (p. 211), the climatic conditions now found in the Arctic regions extended as far south as central Europe. At this time, only plants able to withstand great cold could survive; the former flora of central Europe retreated to the south, and its place was taken by Arctic plants. When at length milder conditions supervened, the plants of the south gradually regained the supremacy, and the Arctic forms of central Europe were restricted to the bleak mountain heights, becoming extinct in the lowlands.

An example of a different kind is found in the curiously scattered distribution of the monkey-puzzle trees, or Araucarias. They are found native on the slopes of the Andes of Chile, in Brazil, in Norfolk Island, in New Zealand and New Caledonia, and scarcely anywhere else. This suggests that Araucarias are extremely ancient types of trees; and the surmise is borne out by geological evidence, which shows that in the Jurassic period (p. 257) they had practically a world-wide distribution.* Since that time they have been gradually crowded out of existence by more modern and better-equipped trees in nearly all parts of the world.

44. THE CHIEF ZONES OF VEGETATION

Plant distribution dependent upon climate.—After what has been said in the foregoing section as to the importance of moisture and temperature as factors in plant habitats, it will be expected that the general distribution of plant associations will have a direct relation to the great climatic zones. The subject must now be considered from this point of view.

Vertical and horizontal distribution.—The influence of elevation in controlling temperature and general climate has been considered on pp. 378 and 477. The changes in climate to be found between the base and the summit of a mountain are naturally reflected in the plant life, so that on ascending a high mountain in the tropics, a traveller encounters a succession of plant types broadly similar to the order in which they would be met with on a journey polewards, and may pass in a few hours through vegetation characteristic of countries thousands of miles apart.

Tropical forests.—In the equatorial belt of climate there are very frequent—often daily—**heavy rains**, amounting to at least 70 inches annually, **with a continuously high temperature**; and on the lowlands and in the valleys the exuberant vegetation grows without hindrance. It forms dense forests, which stretch across Africa, in a band from 100 to 200 miles wide on the north of the Gulf of Guinea and then broadening to cover most of French Congo and the Congo Free State to the great Lakes; and in South America extend over the basin of the Amazon and fill the valleys of other rivers of Brazil. Similar conditions are found skirting the coast lines of the Malay Peninsula and Archipelago. Among the most important, economically, of the plants found in these forests are the various rubber and guttapercha vines and trees of the Congo, Brazil and East Indies; and trees yielding valuable timber—such as ebony, mahogany and rosewood —or drugs (*e.g.* quinine).

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* "In the Carboniferous, Permian, and some later periods a vast continent extended from Eastern Brazil to Australia, including Southern Africa, the Indian Ocean, and Southern India." (J. W. Gregory's "Geology": Dent.)

The winding and coiling creepers and climbers (lianes), the gorgeous orchids and other flowers, are of little commercial importance, but none the less remarkable. In the **secondary forest,** which springs up where the virgin forest has been cleared, are oil palms and sago palms and plantations of rice, manioc, arrowroot, sugar (except in the Congo and Amazon basins), coffee, cacao (cocoa) and tobacco.* Along the sea shore and bordering the estuaries in this belt are found swamps covered with mangrove forests.

FIG. 274.—Scene in a tropical forest.

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* *Rice* is also cultivated in parts of the "temperate" zone where the necessary warmth (70° F. for six months) and moisture are available, but is most successfully grown in the monsoon regions of the tropics. *Coffee* (chiefly in Pernambuco) requires a moist climate and a temperature between 55° F. and 80° F. *Tea* (India, Ceylon, China, Japan and Java) is more hardy, being able to survive occasional cold weather.

Savannahs.—Intervening between the tropical forests and the dry deserts of the trade-wind belts, occur stretches of warm country with a **moderate rainfall** only. Here there are very few trees but **grasses** of various kinds which afford abundant food to herds of grazing animals. In the better watered portions some amount of agriculture is possible. Such savannahs include the African Sudan, the Venezuelan " llanos ", the Brazilian " campos " and the Australian " downs ". A good example of such " downs " is to be seen on the Nilgiri hills in South India.

FIG. 275.—An Egyptian oasis.

The trade-wind deserts.—More than half of the land lying in the trade-wind belts consists of desert. It is in such situations, naturally, that the scanty vegetation which can exist at all will show most markedly xerophytic characters (p. 503). Along the **margins** of the deserts, where the rainfall is slightly more abundant, thorny plants—principally *acacias*—are common. This group has been said to constitute an " acacia-fringe " round all the great trade-wind deserts of the world. Gum arabic, Senegal and other gums are obtained from certain species of acacia. In the **oases** (Fig. 275) and on the margins of rivers flourishes the invaluable date-palm. More typical of the **inner desert** are cacti, various very fleshy species of Euphorbia (allied to the spurges) which assume the most weird shapes, the " ice-plant", and the grasses called esparto or halfa. Many of the desert plants are covered with thick flannel-like coats of hair to prevent loss of moisture. Perhaps the quaintest of all desert plants is the ancient *Welwitschia*, now limited to south-west Africa.

When the rare showers of rain fall in these deserts a host of small herbaceous plants, bearing brilliant flowers, springs up. A few days suffice for germination, flowering and the production of the seeds, bulbs, or tubers, necessary to complete the cycle at the next opportunity.

FIG. 276.—Leaves of sycamore.

Sub-tropical scrub.—Scrub is the name given chiefly to the vegetation which occurs on the desert-fringe of countries having the **Mediterranean type of climate** (p. 488). Lacking the plentiful rainfall necessary for abundant tree growth, it forms a transition between the tropical desert-flora and the forests of the warm temperate regions. On the desert border is found the acacia type of vegetation, and it is this half desert which yields the most valuable gums and resins used in perfumery. The Mallee scrub of Australia consists of eucalyptus bushes. Grapes, oranges, figs and olives are typical products of the Mediterranean climate, and similar conditions in California, southern Australia and Cape Colony make these countries also important centres of the wine industry.

Cotton is an important crop of the sub-tropical zone. It thrives best in a deep, rich soil with a long, hot season, the atmosphere being damp during the period of greatest growth (about 2 months), but becoming drier during the ripening of the crop. (*Maize* (p. 513) also grows most successfully in a climate of this type.) These conditions are found in the southern United States of America, which furnish four-fifths of the world's supply of cotton. India, China and Egypt come next in order in extent of cotton production.

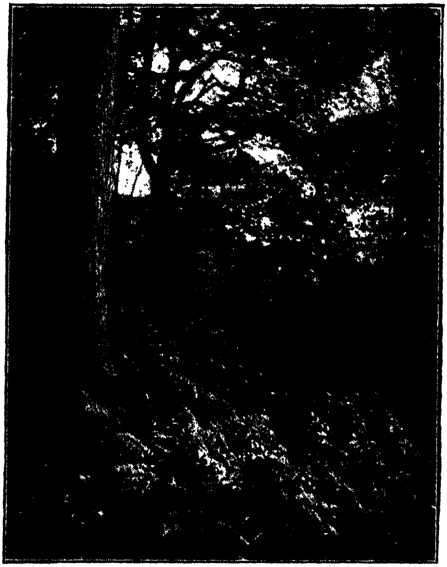

FIG. 277.—Typical English woodland scene (deciduous trees, with bracken, etc.). Photo by W. B. Crump.

The temperate forests.—Reaching northward and southward from the sub-tropical belts to a line which corresponds roughly with the isotherm of 50° F. for the warmest month, those lands which possess a reasonably abundant and regular rainfall are for the most part covered by forests.

In the **warmer temperate regions** and on lowlands, most of the trees are of the mesophytic type, having broad leaves, which give off water vapour freely whenever they are exposed to light. The risk to the tree—entailed by retaining such leaves through a winter considerably colder than the summer—is great, as has been explained on p. 503.

The trees of these regions are therefore **deciduous**, shedding their leaves annually before winter. Typical examples are oak, elm, fig, silk-cotton tree, etc.

Trees, the leaves of which are specially adapted to restrict transpiration (p. 502), however, can retain their foliage safely through the winter of the cooler temperate regions and at elevations where most of the broad-leaved trees have failed to obtain a footing. Xerophytic trees of this kind belong largely to the group of **Conifers** (cone-bearers), which includes the pines, firs, spruces, larches, cedars, cypresses, junipers, etc. Their leaves are more or less needle-shaped and leathery, with breathing-pores sunk below the surface. Larches, however, are deciduous.

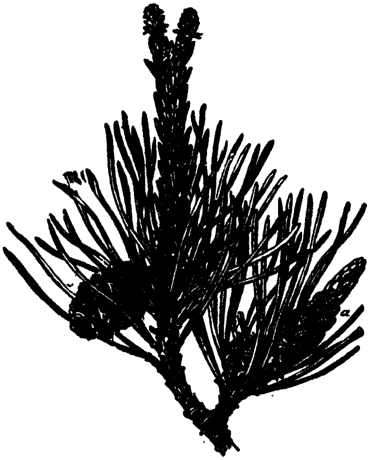

FIG. 278.—Branch of Scotch pine, showing needle-shaped leaves.

Such **coniferous forests** form a belt distantly encircling the North Pole (p. 474). They are the chief source of useful timber, and of wood-pulp for paper-making, etc. In Scandinavia they consist chiefly of the Scotch pine, in Russia of a fir, in Asia of the Siberian larch and —further east—a species of pine. In America, spruce and pine to the west (Fig. 283), and the American larch to the east, of the Rocky Mountains, are the commonest representatives of this hardy family. It is significant that in both the old and the new world the larch thus replaces the pines and firs in the more "continental" climates. There are now no trees in Greenland. The conifers on the western slopes of the Sierra Nevada in California are—after certain eucalyptus trees in Australia—the largest trees in the world ;* next in order of size come the conifers of British Columbia. In the southern hemisphere the coniferous forests are less continuous and more archaic in character. The Araucarias of southern Chile, southern Brazil, New Caledonia and New Hebrides have already (p. 505) been mentioned. Other ancient types of conifer occur in the southern forests of the Andes, in Australia, New Zealand and the Fiji Islands. The conifers also abound in the Himalayas.

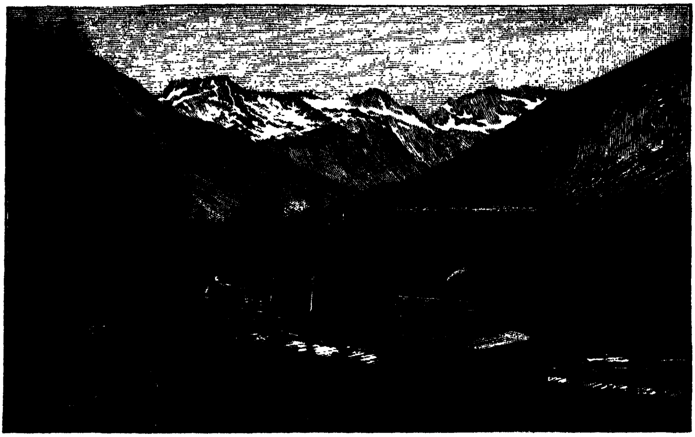

FIG. 279.—Pine forest in the Selkirks (British Columbia).

It is a curious fact that certain hardy and dwarfed broad-leaved deciduous trees—birch in the northern, beech in the southern, hemisphere—are able to grow even nearer the pole than the conifers.

Steppe lands and prairies.—In the temperate zones—usually *to the leeward of the forest regions*, so that they receive a smaller rainfall and experience more continental conditions generally—occur extensive tracts of unwooded land covered chiefly by **grasses** and in the warmer months bright with flowers. These constitute the steppe lands of the old world and the prairies of America. Directly (as cereals) or indirectly (as the food of animals whose flesh is used as meat), the grasses form the chief food supply of the human race.

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* A section of one of these trees, exhibited in the Natural History Department of the British Museum, shows 1335 rings of wood, each of which is believed to represent one year's growth.

From southern Russia, the steppe lands stretch eastward through southern Siberia to China; in South Africa they form enormous plains (veldt); in North America they include the great prairies to the east of the Rockies, and in South America the pampas of Argentina; and in Australia the grassy plains of western Queensland and New South Wales.

The plants known as **cereals** are grasses with edible seeds, and it is, naturally, to the steppe regions that we must look for the principal sources of this all-important food-supply. Rice (p. 507), a cereal, however, requires a higher temperature and a moister climate. "The great cereal lands of the world are found **in the continental interiors in the regions of summer rains,** where the precipitation is sufficient. Roughly, between latitudes 40° and 52°, other conditions being favourable, we find the principal **wheat** belt; but wheat is cultivated much farther north, for example in Asia, and also farther south than the above limits. **Barley** grows over a much wider belt, both poleward and equator-ward; **oats** grow north of wheat, and corn (*i.e.* **maize**) grows south of it (p. 510). In the higher latitudes, with shorter summers, it is more and more difficult for cereals to ripen. . . . It is worth noting, that the wheat harvest in Argentina usually begins late in November in the north, and progresses southward until February; in India the harvest begins late in February in the south, and progresses northward until early in May. The Indian and Argentine wheat thus come to market in what is known as the 'dead season' in the other wheat countries, and therefore have an important effect on prices." *

Already more than one-third of the population of the world are regular consumers of wheat bread. About 55 per cent. of the wheat is grown in Europe, and about 20 per cent. in the United States. The small but increasing quantities of wheat grown in the Punjab and other parts of India are of importance because they are harvested at a different time to the crops of Europe and America.

The climate of parts of the Indian peninsula is very favourable to the growth of grasses. In the Satpura districts, as well as in the

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* Ward's "Climate" (Murray).

Nilgiri hills, where the rainfall is most abundant and the winters are mildest, and also in the western Deccan and on the Shillong plateau, the rich *pasture grasses* supply the means for successful cattle raising and thus allow opportunities for dairy farming, which are not fully taken advantage of. These conditions are also suitable for grazing sheep on the hillsides. In the drier and warmer districts of Madras and elsewhere, arable (*i.e.* ploughed) land exceeds permanent pasture considerably, and forms the principal *wheat* area of the Punjab. In the British Isles, wheat requires a mean July temperature of at least 56° F., and an annual rainfall of less than 30 inches. *Barley* has a wider range, while *oats* are so hardy that they can be grown under more variable conditions of rainfall and temperature.

As the forest regions of the temperate or cooler zones are succeeded to the leeward by the steppe or grass lands, so these in their turn give place on their " continental " side to **deserts**, especially where surrounding high land has co-operated with distance from the sea in drying the prevailing winds. The " temperate " deserts reach their greatest development in the interior of Asia (*e.g.* Gobi), but are found also in Australia, North America (in south-eastern California and in Arizona) and Patagonia. The scanty plants show xerophytic characters (p. 503).

Vegetation of India.—The following extracts taken from H. F. Blanford's little book, " The Rudiments of Physical Geography for use in Indian Schools " (Macmillan) are based on Hooker and Thomson's introductory essay to the " Flora Indica ", to which work, as well as to the *Himalayan Journals* of the former author, the reader is referred for further information on the vegetation of the Himalayas.

" The richest and most luxuriant and varied vegetation is to be found where the rainfall is abundant and frequent at most seasons of the year, the air always moist, the temperature warm and equable, varying little between day and night, or between summer and winter. Such is especially the condition of islands in tropical seas, the Malay peninsula, the western and southern parts of Ceylon, and the Malabar coast of India. Here is especially the home of the palms, the plantains, bamboos, orchids, cycads, the screw-pines, and trees producing large and brilliant flowers. Among cultivated plants, the more delicate spices, nutmegs, cloves, allspice, and cinnamon, are restricted to these regions. So also is the breadfruit tree (closely allied to the Jack-fruit) ; and the useful coco-nut palm flourishes only within a short distance of a tropical sea. The low damp valleys of the central Himalaya, Assam, and Cachar are almost equally rich, enjoying a humid climate, and a copious rainfall well distributed through the year; while neither the summer heat nor the winter cold are ever excessive. Some of the more delicate tropical plants indeed do not grow here. But no one who has ever roamed through the dense forests of these regions can have failed to be struck with the riotous wealth of their vegetation. Here the gigantic boles of tall umbrageous trees, Terminalias, Bauhinias, with their peculiar bi-lobed leaves, Bombax (tree-cotton), and numerous Leguminosæ (pod-bearing trees), and the intricate tortuous root-stems of the figs, are almost concealed by a rich clothing of orchids, ferns, mosses, the smooth drooping leaves of the Pothos, and the closely embracing stems of gigantic creepers, such as the *Bauhinia Vahlii*, that, high above the spectator's head, throw their twining branches from bough to bough, and from tree to tree, binding them together with great rope-like festoons. And the ground is rendered impassable by the long thorny stems and feathery leaves of the rattan palm, by screw-pines, and dense growths of bamboo, intermingled with plants of the Ginger and Turmeric order, orchids, ferns, grasses, and the gaudy-flowered Bignonias and Acanthaceous creepers.

"On the drier plains of the interior of India, a totally different and less rich vegetation is met with. Forests are rare except in the neighbourhood of hills, and for the most part a low bushy scrub of jujube (a vegetable luxury of the bears), dwarf thorny acacias and the stemless date-palm, prevails; and among trees the useful babul, the mahowa, tamarind, and sal, are conspicuous. Oleanders, with sweet-scented flowers, grow on the margins of streams; and in dry places, the grey-flowered madar, and the succulent prickly pear and (generally) leafless euphorbias, are common. In Upper India, the tamarisk abounds, and forms dwarf forests yielding abundant firewood. The date-palm and the tal are the only palms that flourish in these dry regions, and these are cultivated abundantly for the sake of their rapidly fermenting juice.

"Among cultivated plants the varieties of Sorghum known in southern India as *Cholum* and *Cumboo*, in northern India as *Bajra* and *Jowari*, and Millet (*Raji*), are important food grains. Rice is cultivated not only on the swamps of the great river plains, and on flat terraces artificially irrigated from tanks, but sometimes as a dry crop on the lower mountain slopes. These and various pulses—Indian corn, in the hills, and in northern India and a part of the Central Provinces, wheat and barley—are the staple food of the people. The sugar cane, tobacco, the areca nut and betel pepper; oil-seeds such as mustard, rape, sesamum (till or gingeley), the ground-nut and the Palma Christi (castor-oil bean); fibrous plants, such as jute, flax, hemp, and cotton; dye-plants such as safflower, arnatto, indigo, and Indian madder; and spices and condiments such as cardamoms, chilies, ginger, and turmeric,—are also among the more important articles of field and garden produce in India. On the hills of southern India and Ceylon coffee is largely cultivated, but does not grow on the plains; and on the lower slopes of the Himalaya and the eastern hills of Bengal and along their foot the tea-plant has now become an important and increasing article of produce. Its cultivation is, however, limited by the condition that it requires more or less rain during the greater part of the year, and it will not thrive therefore on the hills of the interior of the peninsula where it is exposed for some months to a dry, hot atmosphere and a burning, unclouded sun.

"Ascending the Himalaya, we gradually leave the tropical vegetation of the lower slopes, and, in Sikkim and Bhotan, at a height of 4000 or 5000 feet, we find ourselves in forests, the prevailing character of which resembles that of the forests of southern Europe. Oaks, walnuts, chestnuts, and magnolias, with the useful toon, are among the commoner trees; and beneath them flourishes a bushy undergrowth, in which may be distinguished the wild raspberry, and the *Daphne*, the bark of which furnishes the material for the tough paper largely manufactured in Nepal. Ferns are still abundant; the tree trunks are often clothed with thick tufts of white hair-like mosses, and beautifully tinted *Selaginellas* cover the exposed rock surfaces. Higher up, from 8000 to 10,000 feet, this forest is replaced by rhododendrons and, in the interior of the hills above the latter elevation, by pines, the most characteristic and conspicuous of Alpine trees. In the N.W. Himalaya, where the climate is dryer than in Sikkim, the lower forests are less luxuriant and varied, and trees of the pine family, including the beautiful and valuable *Deodar*, are more characteristic at lower levels. Indeed, pines, firs, and cedars, oaks, and rhododendrons constitute the greater part of the forests above 3000 or 4000 feet, and are frequently restricted to the northern slopes. Wheat and barley are cultivated in the valleys up to a height of 15,000 feet, and most of the European fruits, apricots, apples, pears, peaches, grapes, cherries, walnuts, etc., flourish far better than in Sikkim, where the climate is too moist and the sky too cloudy to allow them to ripen. Above 15,000 feet, vegetation of any kind is very scanty, although, as stated by Drs. Hooker and Thomson, plants may be gathered up to 19,000 feet, on the margins of rills formed by melting snow."

The tundra.—Polewards (p. 474), the northern forests of coniferous trees and stunted birch are succeeded by a frozen treeless desert called the tundra (Fig. 280), or, in Canada, the " barren lands ", which reaches to the shores of the Arctic Ocean. In summer the surface thaws sufficiently to produce a more or less swampy plain on which grow ferns, mosses and lichens, tiny willows and junipers, and also a number of Arctic herbaceous flowering plants which mature quickly and deck the ground with blossoms of astonishingly brilliant colours. The extremely small size of Arctic plants is explained partly by the shortness of the growing season and the general severity of the climate, and partly by the intensity of the summer sunlight, which retards growth. In winter the tundra is frozen hard and covered with snow.

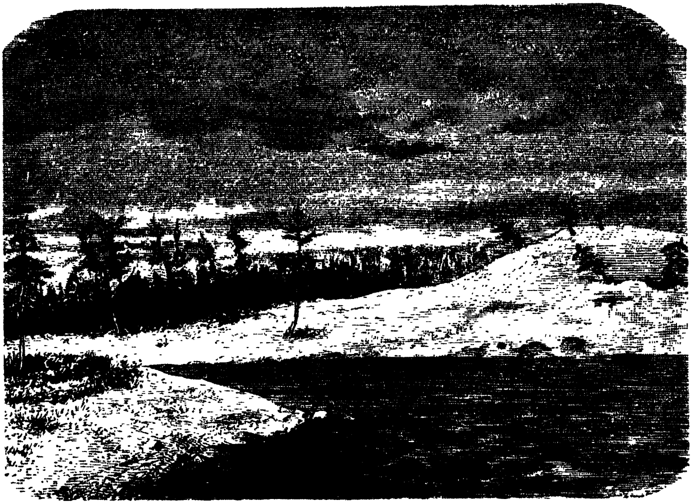

FIG. 280.—The limit of trees in Siberia.

North of the tundra is the perennial ice-cap on which plants are unable to exist.

The distribution of the vegetation belts, with the representative plants of each, is exhibited graphically in the following table, intended for reference only :

	Climatic Zones.	Water Supply.	Average Mean Temperature.	Countries.	Type of Vegetation.	Trees and Shrubs.	Cereals.	Other Typical Plants.
TROPICAL.	Doldrums.	Daily or frequent rains.	Over 80° F.	Peru, Brazil, Upper Guinea, Congo, East Indies.	Tropical Forest.	Rubber and gutta percha vines and trees, ebony, mahogany, rosewood, teak, sandalwood, baobab, sago palm, cinchona.	Rice, Millet.	Banana, manioc (tapioca), arrowroot, some cotton (Peru), coffee, sugar cane (except in Congo and Amazon basins), cacao, tobacco, sweet "potato," etc.
	Equatorial (general).	Summer rains.	Over 80°.	Sudan, Venezuela, Brazil.	Savannah.	As above. Scanty.	Rice, Millet, Maize.	Forage grasses.
	Trade-Wind Belts.	Abundant rainfall on eastern slopes.	Over 70°.	Central America, W. Indies, Guiana, Brazil, S.E. Africa, E. Australia.	Tropical Forest.	As in doldrum zone. Jarrah (Australia).	Maize, Rice.	As in doldrum zone.
		Lowlands and interiors dry.	Over 70°.	Sahara, Chile, Peru, Central Australia.	Desert.	Date palms near water. Acacia.		Alfalfa (for forage), cactus, agave, esparto.
	Monsoon Belts.	Summer rains.	Over 70°.	India, S.E. Asia, N. Australia.	Various.	As in Equatorial. Jarrah (Australia.)	Rice, Wheat, Millet.	Sugar cane, cotton, tea, jute, flax, beans, etc.
SUBTROPICAL BELT.		Winter rains.	60°—70°.	Mediterranean, Cape Colony, Southern U.S.A., S. Australia.	Scrub.	Acacia, olive, grape vine, fig, orange, lemon and other fruit trees, cistus, oleander, laurel, etc. Eucalyptus (Australia). Trees in clumps.	Barley, Wheat, Maize, Sesame, Millet.	Bulbous and tuberous plants, aromatic herbs, tobacco, flax, prickly pear (a cactus), cotton.

TEMPERATE.	Warm Temperate (Marine Type).	Abundant and equable rainfall on western shores and slopes.	40°—60°. Warmest month over 50°.	Central Europe.	Broad-leaved deciduous forests.	Oak, maples, beech, elm, ash, etc., as in England.	Rice (Lombardy), Maize, Wheat, Barley. Oats.	As in England; flax, beet, buckwheat, potato, peas, beans, etc.
				Atlantic and Gulf Plains of U.S.A.	Do.	Do., with magnolia and liquidambar.		
				Western U.S.A.	Coniferous forests.	Sequoia, redwood, etc.		
	Cool Temperate (Marine Type).	Do.		N. Europe, Siberia, Canada, S. Chile, S. Brazil.	Coniferous forests.	Pines, firs, larches; araucaria.		
	Continental Temperate.	Moderate Rainfall.		S. Russia, Hungary, Central Asiatic Plateau, "Great Plains" of U.S.A., S. Africa, Argentina, N. S. Wales, W. Queensland.	Grass land.		Maize, Wheat, Barley, Oats, Rye.	Forage grasses.
	Extreme Continental.	Rainfall scanty or absent.		Arizona, S.E. California, Atacama, Patagonia, Kalahari, Turkestan, Gobi, Central Australia.	Desert			Alfalfa (for forage), sage brush, mesquite, cactus, etc.
POLAR, - -		Low temperature causes physiological drought.	Below 32°. Warmest month below 50°	Circumpolar Europe, Asia and Canada; Alaska.	Tundra.	Dwarf willow and juniper.		Mosses, lichens; Arctic herbaceous flowering plants.

EXERCISES ON CHAPTER XVI

1. State what areas in any *one* of the continents are densely afforested. In which of these areas is the lumber industry most important, and why? Name other products of economic value besides timber which we procure from forests, and state where they are chiefly obtained.

2. Explain (*a*) why the range of temperature at Colombo in Ceylon is very slight; (*b*) why the annual rainfall at Bombay is heavy and falls mainly in summer; (*c*) why wheat flourishes in the Punjab, rice in the lower Ganges basin, and tea on the lower slopes of the Himalayas.

3. What connexion can you trace between vegetation zones and climate zones? Give examples.

4. What climatic conditions are necessary for the existence of (*a*) deserts, (*b*) dense tropical forests? Give two examples of each.

5. There are two main types of forest: where are they found? Contrast them with reference to position, climate, and products.

6. Why does snow stay all the year round in parts of the Himalayas of India, China, West-central Asia and South Europe and not in any part of the British Isles? How do permanent snowfields affect rivers? What kind of trees grow near the snow-line?

7. Where are forests found in Australia? Give reasons for this distribution.

8. What are the reasons for the following phenomena?—

(*a*) the temperature of Iceland is sometimes higher than that of England, France and Spain;

(*b*) the July temperature of Kashgar is often the same as the January temperature of Florida;

(*c*) North Alaska and the region between the Black and the Caspian Seas are both treeless.

9. Name the chief wheat-producing areas of the world, and in regard to each give the time at which the harvest occurs, and the reasons why the harvest comes at the particular time.

10. Owing to peculiarities of climate, the vegetation of the peninsulas of South-east Europe exhibits marked characteristics.

What peculiarities of climate are referred to, and how is the vegetation affected thereby?

11. By reference to *climate*, how would you explain:

(*a*) Why *corn* is grown in Canada and not *rice*?

(*b*) Why certain regions only in the world are suitable for growing cotton?

(*c*) Why Arctic plants are found in the higher Himalaya and Hindu Kush mountains within the sub-tropical zones?

12. What are the geographical conditions necessary for the production of wheat, rice, and cotton? In what parts of the world are they principally grown?

13. How are the successive belts of vegetation arranged in the Sikkim Himalaya ? Account for their character and distribution.

14. Specify, as exactly as possible, the jute-producing regions of the world, mentioning the chief ports of export. What physical conditions favour the growth of jute?

15. Explain why we have such deserts as the Sahara and the Gobi. How does it happen that there are oases in these deserts?

16. Describe and account for the positions of the chief desert regions in the world, and mention any articles of commerce that have been obtained from them.

17. What is meant by Tundra? In what parts of the world does Tundra occur? What constitutes the southern limit? Shortly describe a Tundra region as it appears in (i) winter, (ii) spring, (iii) early autumn.

18. State the chief agricultral products of the Mediterranean region. Specify carefully any other parts of the world which have a similar group of products, and suggest reasons for the similarity.

19. State as precisely as possible the chief rice-producing regions of the world, and describe the conditions most favourable to the cultivation of rice.

20. Describe the distribution and characteristics of the chief coffee-growing regions of the world.

21. State precisely the regions of the world where tea is produced. What are the special conditions required for tea production?

22. What are the chief vegetation regions of Africa south of the Sahara? Indicate briefly the climatic factors which determine them.

23. Contrast the plains of India and the steppes of Siberia with respect to climate and vegetable productions.

24. Where are the wheat lands in Europe? Account for their position, and compare them with any other wheat-growing areas in the rest of the world.

25. The northern limit of wheat cultivation passes near latitude 53° N. in Canada, latitude 58° in Scotland, latitude 60° in Norway, latitude 62° in Sweden, and latitude 63° in Russia. Account for these variations in latitude as regards wheat growing.

CHAPTER XVII

THE GEOGRAPHICAL DISTRIBUTION OF LAND ANIMALS AND MAN

45. THE DISTRIBUTION OF LAND ANIMALS

The dependence of animals upon plants.—All animals obtain their food from plants, either directly or indirectly. Many animals are, of course, flesh eaters, living upon other animals ; but in such cases the prey itself is usually vegetarian. To the wolf and the lamb alike, life would be impossible in a world without plants. It follows from this that the distribution of animal life on the earth must exhibit a general correspondence with that of plants. In deserts, whether of sand or of snow and ice, the dearth of plants must be accompanied by a scarcity of animals. Where, on the other hand, exuberant plant life provides an abundance of food, animals will usually occur in large numbers.

Differences of environment.—Animals, like plants, occur in certain restricted habitats, for which they are fitted by their nature. The idea of beavers in the Sahara, or of sloths in a Siberian steppe, is absurd to one knowing anything of the habits of these animals, because the conditions of their actual lives are the precise opposites of those suggested. We might expect to find an animal living where the conditions were suitable for its maintenance, but nowhere else. There is nothing intrinsically absurd, for example, in the thought of sheep in New Zealand, of tigers in South America, or of bears in South Africa. We know that sheep farming is highly successful in New Zealand ; it seems likely that for tigers tropical South America, and for bears many parts of South Africa would be among the happiest of hunting grounds. It is nevertheless a fact that there

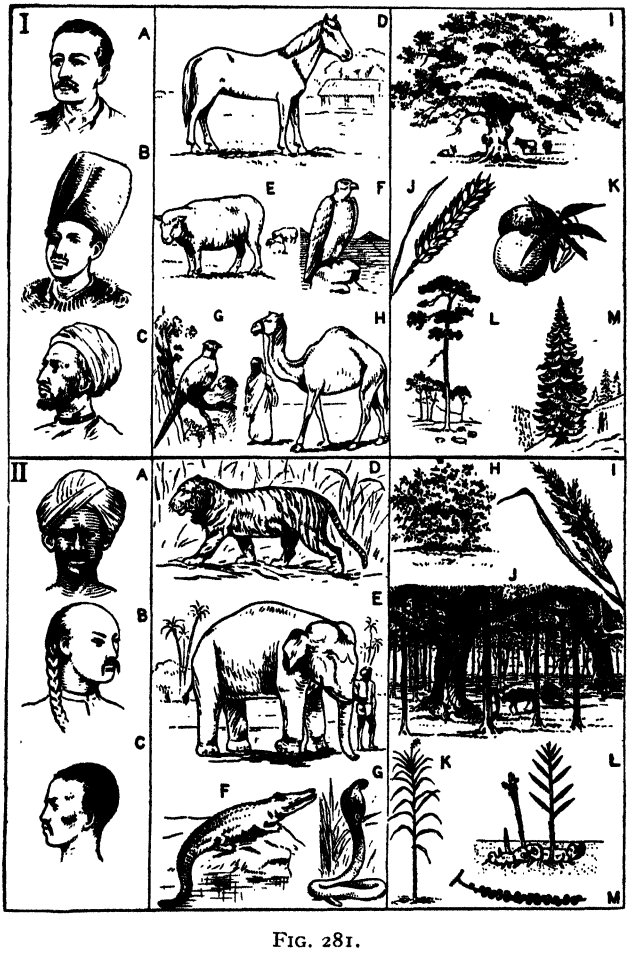

FIG. 281.

I.—A, European ; B, Persian ; C, Arab ; D, Horse ; E, Sheep ; F, Eagle ; G, Pheasant ; H, Camel ; I, Oak ; J, Ear of wheat ; K, Orange ; L, Larch ; M, Pine.

II.—A, Indian ; B, Chinese ; C, Malay ; D, Tiger ; E, Elephant ; F, Crocodile ; G, Cobra ; H, Tea bush ; I, Rice (paddy) ; J, Part of Banyan tree ; K, Sugar-cane ; L, Ginger ; M, Pepper.

were no sheep in New Zealand until they were taken thither by man, and it is safe to assert that only in menageries are tigers to be found in South America, or bears in South Africa. Evidently it is necessary to distinguish between the animals which, so far as search reveals, have existed in or are **indigenous** in a region, and those which were not originally present but have been **introduced** by human agency and have established themselves where the conditions were suitable.

Barriers.—The facts just mentioned, and others of a similar nature, show that many species of animals have been unable by their own efforts alone to reach all the regions suitable for their maintenance. Animals are prevented, in fact, by **barriers** from dispersing to an unlimited extent. For creatures which, like monkeys, cannot swim or fly, even a river or a small arm of the sea may be impassable. A stretch of desert to many animals, a snow-clad mountain range to others, may similarly prove permanent obstacles to migration.

The significance of discontinuous distribution in the case of animals is precisely the same as in that of plants (p. 505). " The greater the facilities for the transport of any species across a given barrier, the less significance will attach to its occurrence on both sides of the barrier. Conversely, when a species having few or no facilities for dispersal is found on opposite sides of an important barrier, the natural conclusion is either that the barrier is of comparatively recent formation, and that the two areas separated by it were once so to speak, in zoological continuity, or that the species in question is a very ancient one, and was widely dispersed at a time when the arrangement of the land surface was very different from what it is at the present day. For instance, the occurrence of strong-flying birds, such as gulls and cormorants, in widely separated countries, is a fact of no significance in determining the mutual relationships of the faunæ of those countries. But the occurrence of the same species of fresh-water crayfish—to which the narrowest arm of the sea is an insuperable barrier—in Great Britain and the European continent, is explained only by the fact—of which there is independent evidence—that the English Channel is of recent formation ." *

" Many of the larger animals of India, such as the elephant, the rhinoceros, the lion, leopard, antelope, gazelle, and crocodile, are closely related to African forms, though, except in the case of the lion and leopard, not identical with them. Others again, such as the

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* Parker & Haswell's " Text Book of Zoology ", vol. ii, p. 591 (Macmillan).

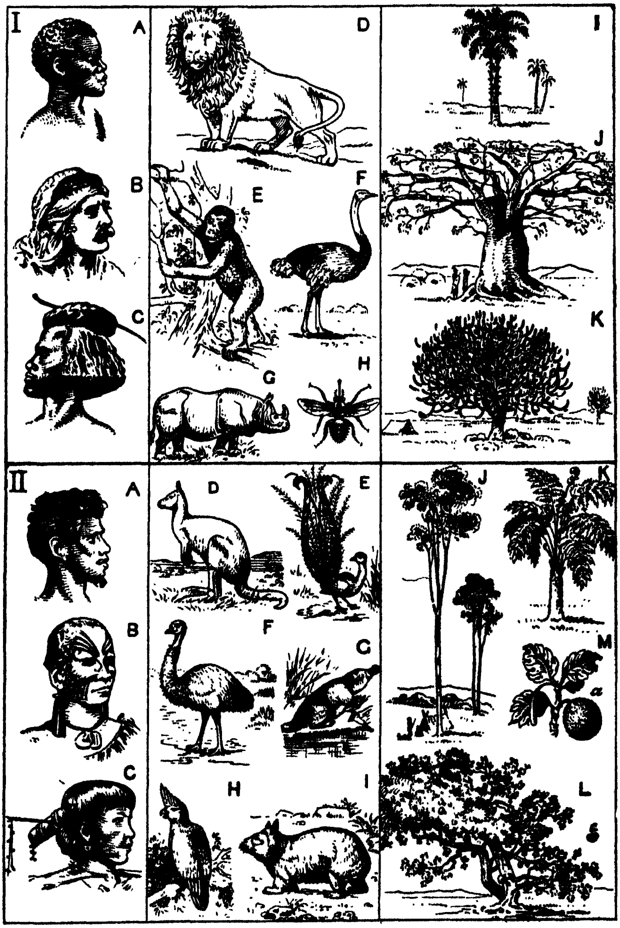

FIG. 282.

I.—A, Negro ; B, Bedouin ; C, Nubian ; D, Lion ; E, Gorilla ; F, Ostrich ; G, Rhinoceros ; H, Tsetse fly ; I, Oil palm ; J, Baobab tree ; K, Euphorbia.

II.—A, Australian aborigine ; B, Maori (old type) ; C, Philippine type ; D, Kangaroo ; E, Lyre bird ; F, Emu ; G, Duck bill water-mole ; H, Cockatoo ; I, Wombat ; J, Eucalyptus tree ; K, Tree fern ; L, Bread-fruit tree ; M, Fruit of bread-fruit tree.

common black bear, are peculiar to India and are not found elsewhere; while the tiger ranges throughout India and the whole of south-eastern and parts of central Asia, as far north as the Caucasus on the west, and the Amoor in eastern Asia. The gibbons, or long-armed tailless apes of Eastern Bengal (*and Assam*) are not to be met with anywhere to the westward, but are numerous throughout the Malay peninsula, Sumatra and Java. The lungoors or Hirmiman monkeys, of which there are several kinds, range throughout India and Ceylon, the Indo-Chinese region, and the Malay peninsula, but do not occur beyond the Himalaya, nor in countries to the west. The loris of Ceylon, the so-called flying lemur of the Malay peninsula, and the slow-paced lemur (*Sharmindi billi*) of Bengal, are representatives of a family of monkey-like animals which occur most abundantly in Madagascar, and are not to be met with in other parts of the Asiatic continent. On the whole, the fauna (or whole animal world) of India is a mixture of forms: some related to those of western Asia and Africa, others to those of eastern or south-eastern Asia, and a few peculiar to the country or with their nearest relations in the islands of the South Indian Ocean and South Africa" (H. F. Blanford).

The occurrence of tapirs in Further India and Brazil, and nowhere between, is, similarly, evidence of the antiquity, and former wide distribution of these animals.

"If several countries connected together have the same kind of climate, the vegetation is either more or less similar throughout, or only varied according to the nature of the soil and exposure; mountain slope, meadow, swamp, and sandy plain, each bearing its characteristic plants; or there is a gradual passage from one extremity to the other; but any great difference of climate is accompanied by a corresponding change in the character and abundance of the plants. Countries, on the other hand, which are disconnected, and have been so for long geological periods, though they may closely resemble each other in point of climate, have very different kinds of vegetation. There is little in common between Africa and Australia, though some African plants range as far as India. . . . Similar remarks apply to animals" (H. F. Blanford).

From such considerations it becomes possible to understand why, between the animals native to England and those indigenous to Japan there is less difference than exists between those of northern and central Africa (separated by the barrier of the Sahara), or between those of Australia and New Zealand (separated by the barrier of the Tasman Sea). The native fauna (animal population) of

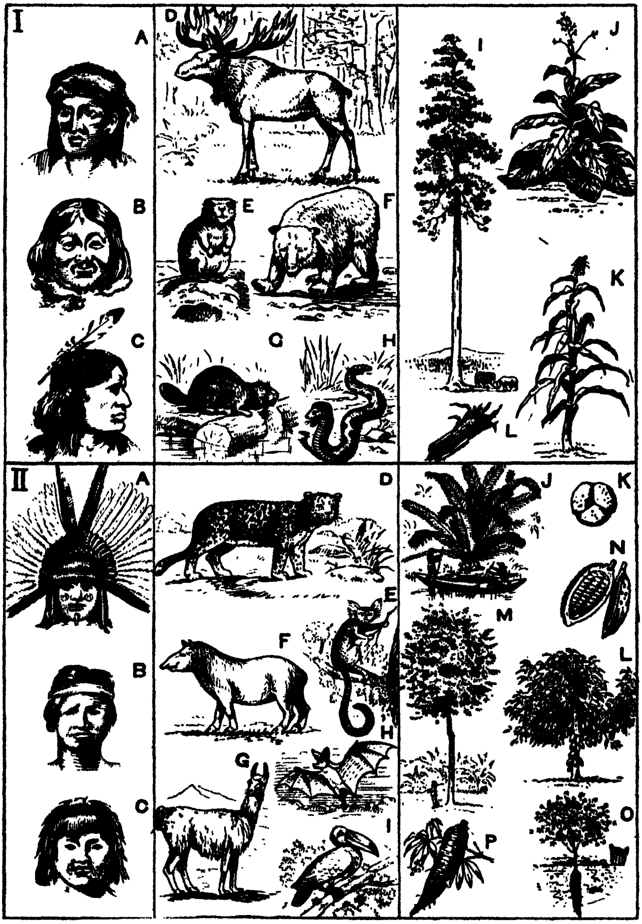

FIG. 283.

I.—A, Type from New Mexico; B, Eskimo; C, Red Indian (North America); D, Elk; E, Prairie dog; F, Grizzly bear; G, Beaver; H, Rattle-snake; I, Douglas pine; J, Tobacco plant; K, Maize; L, Cob of K.

II.—A, Brazilian Indian; B, Patagonian; C, Tierra del Fuegian; D, Jaguar, E, Marmoset; F, Tapir; G, Llama; H, Vampire bat; I, Toucan; J, Ivory palm; K, Fruit of J; L, Cacao tree; N, Fruit of L; M, Rubber tree; O, Maniac palm; P, Manioc tubes (tapioca is got from it).

England is so like that of Europe that it is said to be **continental** in character ; that of New Zealand is peculiar to itself and therefore is described as **insular.**

Continental and Oceanic Islands.—In dealing with the fauna and flora of islands, " we must distinguish between those lying close to continents, with which, at some former time, they have generally been connected, and those which occur isolated, far out in the ocean. Of the first class, called **Continental Islands,** we have an excellent example in Ceylon, which was originally a part of India, and is now separated from it only by a shallow channel. On the other side of the bay, the Andaman and Nicobar Islands, with the Cocos Islands between the former and Cape Negrais, are evidently the summits of the submerged portion of a chain of mountains which runs down Arakan to Cape Negrais and there plunges beneath the sea, rising again in Sumatra, and forming the backbone, so to speak, of that island. On the other hand, such islands as St. Helena and Ascension in the South Atlantic, the Mauritius and Seychelles in the South Indian Ocean, and the islands of Polynesia in the Pacific, have probably never been connected with any continental land. Coral islands are also of this latter class. All such are distinguished as **Oceanic Islands.**

" Now in respect of vegetation and their native animal inhabitants (under which term we include not only quadrupeds, but birds, reptiles, insects, snails, and all other members of the animal kingdom) these two classes of islands exhibit a striking diversity. The animals and plants of continental islands are either of the same kind as those of the neighbouring portion of the continent, or are closely related to them. But generally the kinds are less numerous. Ceylon, for instance, is in this way nearly related to the southern extremity of India. But neither the tiger, the hyena, nor the hunting leopard occur in the island. On the other hand, as is frequently the case in such islands, it possesses some forms, both of animals and plants, which are restricted to it. . . . In like manner the flora and fauna of the Andaman and Nicobar Islands are nearly related to those of the Malay peninsula, but they possess some forms not occurring on the latter, while a much larger number common on the mainland are not to be found on the islands.

" With oceanic islands the case is different. The whole number of forms on such islands is in general small, but these are as a rule peculiar, and frequently very unlike those occurring anywhere else. Thus, until visited and colonised by Europeans, New Zealand possessed no species of mammal (or animal that suckles its young), except one kind of rat, two or three bats, and the seals and whales of the coast, but it possessed a peculiar group of wingless birds, some of gigantic size, nothing like which is known to occur elsewhere. Again, the Galapagos Islands are the only place in the world in which marine reptiles now live ; and out of twenty-six kinds of birds which these islands possess, at least twenty-one are peculiar to them. A gigantic tortoise (miscalled *Testudo Indica*, or the Indian tortoise) and a large palm tree, the seed of which resembles two coco-nuts united, are found only on the Seychelles ; and a very peculiar kind of gigantic ground-pigeon, the Dodo, formerly lived on the Mauritius; but being incapable of flight, and therefore easily caught and killed, it has long since become extinct." (H. F. Blanford).

The zoo-geographical regions.—Zoologists have mapped the surface of the earth into regions in order to group together countries the native faunas of which have most in common, and to distinguish between countries which have widely different indigenous animals. Fig. 284 shows such a division into regions based chiefly on the distribution of the hairy quadrupeds (mammals).

Animal life in the tropics.—In the tropics, conditions are specially favourable for animal life, since abundance of food is provided by the luxuriant plant growth. The large animals occur in the savannahs, however, rather than in the dense forests. Interesting differences are to be found in the animals characteristic of tropical South America, tropical Africa and the Oriental region, although the conditions of life are in so many respects similar.

In **tropical South America** are found broad-nosed monkeys, opossums, sloths, armadillos, ant-eaters, the jaguar, lama (related to the camel), peccary and a species of tapir ; besides humming-birds, the condor of the Andes, the large-billed toucans and other strange birds —all unknown in tropical Africa or Asia.

Tropical Africa is the home of such " narrow-nosed " monkeys and apes as the gorilla, the chimpanzee and several baboons, as well as of the lemurs, of the giraffe, zebra and hippopotamus, the African elephant, rhinoceroses, the camel, lion and leopard. Besides these

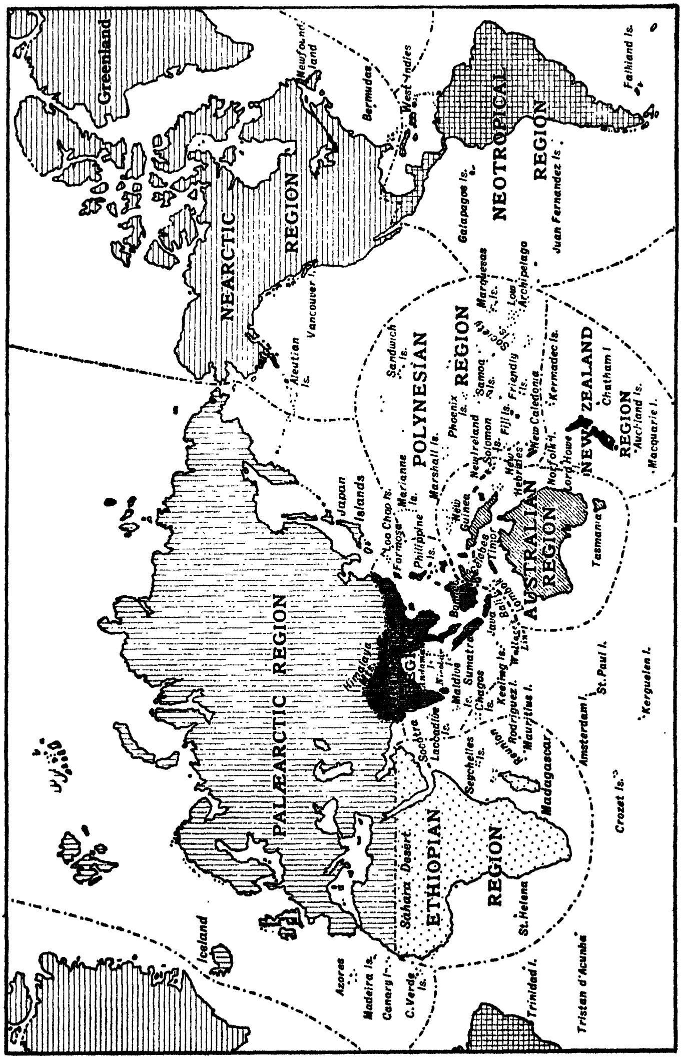

FIG. 284.—Zoo-geographical regions of the world.

mammals there are—among birds—the ostrich, the hornbills (which much resemble the toucans of tropical America), and the sun-birds (which resemble the humming-birds). The secretary-bird is purely African in range. Tropical Africa is remarkable for the great abundance of hoofed animals (ungulates).

The **Oriental region** possesses many groups of animals (*e.g.* elephants and rhinoceroses, higher apes and lemurs) in common with tropical Africa. On the other hand, the tiger, and several species of bear and deer, which are here abundant, are not found at all in the Ethiopian region. Tapirs occur here, as well as in tropical South America, but nowhere else.

Animals of the temperate zones.—The **north temperate zone** includes most of Europe, of Asia and of North America. In the " old world " it is separated, zoologically, from the tropics by the desert of Sahara and by the Himalayas ; while in the new world North and South America were separated by the sea within recent geological times. Throughout this zone there is a marked similarity in animal life ; although certain mammals (*e.g.* opossums), birds (*e.g.* humming birds), reptiles (*e.g.* rattlesnakes and iguanas) and members of other groups occur in North America, but not in Europe or Asia ; and the Palæarctic region, on the other hand, has a number of forms (*e.g.* wild horse and ass) which are absent from North America.

Within the north temperate zone exist, as has been seen, marked climatic differences and correspondingly distinct belts of vegetation ; and it is natural that in each belt the conditions of life are reflected in its animal population. The opossums of North America, the squirrels of both continents, with other tree-dwelling mammals as well as birds, haunt the forests. The grazing, hoofed mammals are found chiefly on the steppes and prairies, where the grass and other herbage affords a supply of food to herds of bison, antelopes and (in the old world) buffaloes ; and the gregarious burrowing marmot (commonly called the prairie-dog) of North America shows another adaptation to the same environment. The irregularity of the rainfall, and consequently of the food supply, of certain steppe lands tends locally to keep down the numbers of animals which multiply slowly, and gives a relative advantage to such prolific creatures as rodents—rats, mice, rabbits, lemmings, hamsters, marmots, etc. Peculiarly at home in the lands transitional between the steppes and the deserts of Africa and Asia, are the camel, the horse, the wild asses, and sheep and goats.

In **South America and South Africa** no general barrier exists between the tropical and temperate zones. In each continent suitability of habitat is the only factor of great importance which distinguishes the tropical from the temperate faunas, so that no hard and fast line can be drawn between them. In temperate South America, the llama, which roams over the pampas, and the vizcacha (a rodent, which, like the prairie-" dog " of North America, constructs underground cities) are characteristic. The South American " ostriches " —more correctly called " rheas "—are different in many respects from the true ostriches of Africa, but of very similar habits. The American humming-birds reach southward to Tierra del Fuego ; in South Africa—as elsewhere in the old world—humming-birds are absent, but are replaced by the sun-birds. The Cape " ant-eater " has but a distant relationship with the true ant-eater of South America.

The Australian region.—While geological evidence points to a relatively recent land connection between Asia and North America, and between the British Isles and Europe, there is reason to believe that Australia and the neighbouring islands have been separated from Asia for a very much longer interval of time. Apparently the isolation of the islands to the south-east of Wallace's line (Fig. 284) took place before the mammals common in other parts of the world had had time to migrate thither : if indeed they had come into existence at all by that period. This view explains why, at the present day, all the **marsupials** or pouched animals (including kangaroos, wombats, bandicoots, Tasmanian devil, etc.) with practically the single exception of the opossums in America—besides all those simplest of mammals the **monotremes,** which lay eggs—are confined to this region. Animals closely related to the marsupials and monotremes of to-day once existed in other parts of the earth, as their fossil remains testify ; but they were unable to withstand the competition of the better-equipped mammals which presently appeared, and they therefore became extinct. That fortunate section which had been marooned in the Australian region, however, being free from such interference, flourished, and in due course gave rise to extremely diverse types ; carnivorous, herbivorous, burrowing and tree-haunting habits all being found among various marsupials. The only mammals of the higher orders which reached the region before civilised man were the dingo or Australian wild dog, and a few rats, mice and bats. The indigenous birds of the Australian region are in many respects equally peculiar, for they include the emus, cassowaries, birds of paradise, cockatoos, etc., which are found native nowhere else.

In **New Zealand** and the neighbouring islands even marsupials and monotremes are absent, and the only native land mammals are two species of bat and perhaps a rat. Many of the native birds are restricted to the region, and a large proportion of them are flightless (*e.g.* the kiwi or apteryx). The reptiles also form a curiously unique assemblage.

It will of course be borne in mind that the advent of civilised man in Australasia has brought about a complete redistribution of animal life there, in respect not only of numbers, but still more of kinds. The herds of cattle and flocks of sheep now occupying wide tracts of land, and the disastrous extent to which rabbits have multiplied, illustrate strikingly the disturbance caused by human interference with the natural balance of animal life.

Animals of the polar zones.—The increasing scarcity of plants in the higher latitudes allows only a relatively small number of animals and kinds of animals to live within the polar zones; while the severity of the winters explains the thick fur which is so characteristic of circumpolar mammals generally. As might have been expected, the animal life is on the whole more abundant near the coast, where a supply of food is obtainable from fish. Inland, the animals are mostly herbivorous.

In the **south polar zone** very few of the larger animals have yet been found. The Patagonian sea lion—one of the "eared" seals—occurring on the coasts of the southern extremity of South America and of some of the neighbouring islands, is the best known mammal. The penguins are the most characteristic birds of the Antarctic islands; they extend from the Falklands to New Zealand, and are not found further north than the Cape of Good Hope.

In the **north polar zone,** among carnivores are found the polar bear, the Arctic fox, the glutton or wolverine, the walrus and certain species of seal. An "eared" seal, known as Steller's sea bear, forms one of the chief articles of food to the natives of the Aleutian Islands, and furnishes also the materials for many of their garments. Of hoofed animals the reindeer (called in America the caribou) is of vital importance to the nomadic peoples inhabiting the tundra. It feeds chiefly on lichens and mosses, to obtain which it wanders northward in summer and southward in winter. By the races who have more or less domesticated it, the reindeer is trained to draw sledges, and its milk, flesh and skin provide food and clothing. The elk or moose and the musk ox are also circumpolar. The polar hare and the lemming (which are rodents), and the ptarmigan among birds, also belong to this zone. Reptiles are absent. Many Arctic animals hibernate during the coldest months; while in the summer their numbers are increased by migratory birds which have come north to breed.

It is interesting to note that during the glacial epoch (Fig. 135), Arctic animals flourished in Britain, where fossil remains of the glutton, cave bear, elk, mammoth (living on till later in Siberia) are found in caves and glacial drift. With the retreat of the ice they migrated northward, and some became extinct.

Protective coloration.—A remarkable feature of many animals is the extent to which their coloration renders them inconspicuous among their characteristic surroundings. The advantage of thus being able to avoid being noticed by their enemies or prey—or both—is obvious. Desert animals, for example, are usually tawny in colour ; the denizens of jungles are striped or spotted ; and many of the beasts and birds of the snow-covered tundra are white, at least in winter.

46. THE DISTRIBUTION OF HUMAN POPULATION

1. Dependence on climate.—Examine a population map of the world. What parts of the earth are uninhabited or have a population of less than 1 person per square mile? Which of these regions fall in the polar zones, which in the temperate zones, and which in the tropics? Which of them have an oceanic and which an extreme continental climate? If possible compare, in the case of Africa, India, Australia and South America, the population map with the rainfall map. Is the population, in general, greatest where the rainfall is greatest and least where the rainfall is least, or not? What exceptional condition is found in South America? Can you explain it? Judging by population and rainfall maps of India, in what areas do you suppose the distribution of population is respectively most and least plainly affected by the rainfall? Contrast in this respect Abyssinia and Italy.

2. Climate and trade routes.—Compare a map of prevailing winds with a commercial chart showing trade routes. How many of these routes do you suppose were originally decided by the winds?

3. Dependence on productions.—(*a*) Compare a geological and a population map of the *British Isles.* What correspondence exists between the positions of coalfields and most densely populated areas? What densely populated areas have no obvious relation to coalfields? Refer to a vegetation map of the British Isles and see whether it affords any explanation of the differences in population of the various non-manufacturing districts. Write notes of any conclusions you arrive at. (*b*) From geological and population maps of *Europe* make a list of districts in which density of population is plainly associated with the presence of Coal Measures. Do the same for the United States of America. Do you find a similar association in India?

4. Dependence on geographical position. (*a*) *Alluvial plains and deltas* (pp. 187 and 189).—From the population map of the world, make a list of six rivers, the lower parts of which flow through areas of specially dense population. In what parts of Europe do alluvial plains or deltas seem most obviously associated with dense population?

(*b*) *Positions of towns.*—(i) Find the positions of the following towns, and account for their names: Aberdeen,* Coblenz,† Bath, New York, Saarbrück,‡ Edinburgh,§ Salzburg,§ Dartmouth, Leningrad or Petersburg, Allahabad or Pryag,¶ and Carlsbad.‖ Examine orographical and other maps, and try to explain the special advantages of position possessed by London, Paris, Marseilles and Vienna before the introduction of railways. Do the same for Delhi, Kabul, Quetta, Dacca and Mandalay (Amarapura).

(ii) Opposite what great continental river mouth does *London* stand? How is this an advantage in time of peace and a disadvantage in time of war? What advantages of water supply does London owe to the Thames and the geological structure of the London basin (p. 177) respectively? How did the Thames make it easy for London to communicate with the interior of England and with the Bristol Channel by land? How is Calcutta favoured by the estuary of the Hooghly? Why were the positions of Port Canning and Diamond Harbour respectively found to be inferior to that of Calcutta?

(iii) What river valleys converge on *Paris*? Which of these valleys communicate with other valleys and gaps to allow ease of access to Belgium, Germany, Switzerland, Italy and south-east France? What advantages of position has Paris over Rouen?

(iv) What geographical advantages are possessed by Calcutta and Chittagong respectively over Vizagapatam? What danger has Vizagapatam escaped by being built so far to the south of the flood-delta of the Mahanadi? What are the most natural routes from Vizagapatam to the Central Provinces, Central India and the Deccan as compared with Coconado?

(v) What river valleys and passes could give Kabul access to the Plain of Peshawar, the Arabian Sea, the Indus Valley and the Caspian Sea respectively? What routes would a railway follow in each case?

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* *Aber* (Celtic) = a confluence.

† *Coblenz* = Lat. *confluens*.

‡ *Brücke* (Germ.) = a bridge.

§ *Burgh* (Teut.) = a fortified place.

¶ *Pryag* (Sanscrit) = confluence.

‖ *Bad* (Germ.) = Spa or bath.

H. F. Blanford wrote: "Man, the highest member of the animal kingdom, with some of the higher forms of which he has perhaps more in common than most persons who are not naturalists are disposed to allow, is found to obey laws of distribution similar to theirs; but owing to his vastly greater power of moving from place to place, and of adapting himself to varying circumstances, his distribution is world wide. Obstacles, such as mountain chains and oceans, insuperable to them, are overcome by him under the promptings of his superior intelligence. The discovery of fire, and of the means of providing artificially the clothing with which he is not endowed by nature, together with his powers of assimilating food of many and varied kinds, enable him to live and reproduce his kind under extreme conditions of climate that would be fatal to creatures less gifted than he. So long as even savage man has to contend with those obstacles to his dispersion which are opposed by the natural barriers of land and water, by the necessities of food and raiment, and the enmity of wild animals, his invasion of the unoccupied land of the globe may indeed be retarded but is not stayed. . . .

"It is only when man comes to contend for his existence with creatures of his own kind, that the struggle becomes fierce and critical. An invading race must be either very decidedly superior in physical power and energy to that which it invades, or at least physically equal and far more advanced in intelligence and civilisation, to make rapid progress in dispossessing the latter. . . ."

Man's dependence upon climate.—Fundamentally, mankind is quite as dependent upon plant life for food as are any animals. Nevertheless by co-operation for mutual benefit in barter and trading generally, and by the perfection which methods of communication and the transport of goods have reached, human beings find it possible to live at considerable distances from the places at which much of their food is actually grown, or their water supply is actually stored. Most English people, for example, live chiefly on bread made from wheat which was grown thousands of miles away. Being able to import also the materials required for clothing, dwellings and other protections against adverse weather, civilised man can, further, live under more varied conditions of climate than could be borne by any creature not so protected.

Man's relation to the great vegetation belts of the earth, though thus to some extent indirect, is none the less real; for—apart from his ultimate dependence upon plant food—he is like most other living things, plants as well as animals, in being unable to exist with ease in conditions of either extreme dryness or great cold. Of necessity, population must be always small in the deserts and in the polar zones. Dense forests, whether in the tropical or the temperate parts of the earth, also put great difficulties in the way of permanent human settlements and are but thinly inhabited. In such regions the population is densest along the forest borders.

Of the two great factors of climate—temperature and rainfall—the latter has much the greater influence on density of population. That regularity of water supply is of the first importance in this respect is shown by the remarkable manner in which the number of persons per square mile often varies directly with the mean annual rainfall. Parts of India display this very conspicuously, and a similar correspondence is noticeable in Australia and Africa, as well as in Spain. It is natural, also, to find that the population of deserts is grouped round the oases.

Land configuration, by modifying climate, has also a more direct influence on density of population. In the tropics, the high lands are generally more thickly peopled than the valleys and plains, so far as increased altitude is accompanied by increased comfort of life. On the other hand, elevated land becomes colder and less habitable as the poles are approached, and in the higher latitudes the population is greatest at sea level. It is found that in the Alps, and in other mountainous districts where the valleys run east and west, the sunny slopes are to a marked degree more thickly populated than the shaded parts of the valleys.

Prevailing winds not only influenced the progress of geographical discovery (and hence the distribution of population) before the discovery of steamships, but also determined many **trade-routes** across the sea, and so favoured the development of centres of population on these routes.

Population as controlled by production.—Wherever food has to be sought far and wide, the population naturally tends to be nomadic and distributed thinly. Thus, the inhabitants of the tundra, being compelled to accompany the reindeer as these animals wander in search of food (p. 533), are nomads; and in the steppe belts and the desert borders the necessity of searching for **pasturage** for flocks and herds brings about a similar lack of settled abodes of the people of central and northern Afghanistan. In summer the Afghan (Hazarajat) peasants and their cattle and sheep live on the Hindu Kush, where pasture is rich and abundant, but return to the valleys for the winter. Dr. Nansen pointed out that the driftwood carried by the polar current down the east coast of Greenland and up the west coast is essential to the existence of the Greenland Eskimo. The curious result is that the distribution of the Greenland Eskimo is determined by the course which the driftwood takes.

In contrast with the thinness of the population caused by pastoral conditions of life, is the aggregation of human beings into populous villages and cities in the fertile plains where the people are largely engaged in **agriculture**, as is the case over immense areas in the Ganges and other river valleys in India, where rice, millet, wheat, tea, sugar-cane, cotton and jute are extensively cultivated in suitable areas. In other countries, such as those of Europe and North America, towns have grown up round sources of abundant **mineral wealth.** No better example of this could be found than in the Damodar valley where the towns of Raniganj, Asansol, Dhanbad owe their present size almost entirely to the coalfields in and near which they are situated, but these examples are not to be compared with those in Great Britain and Germany and elsewhere. Naturally, great manufactures (often of raw materials, *e.g.* wool and cotton, brought from a distance) have sprung up close to the spots where the all-important coal and iron are found,* and these have increased the density of population still further. Since it is in districts which otherwise furnish little or no means of subsistence that the mineral wealth of England is chiefly found, thickly peopled areas occur there sharply contrasting with virtually unpopulated districts close by. In India manufacturing industries have usually sprung up in and around the large towns—Calcutta, Bombay, Nagpur, Madras, etc.—which existed previous to the development of the mineral resources of this country half a century ago, and it is in relatively rare cases that factories have been erected close to the coalfields. Even the great Tata Iron & Steel Co. was built on a site where water was abundant, equidistant from the supplies of coal, iron ore and limestone. However, as industries develop in India it is certain that the chief centres will be located near the coalfields as in other countries, when the distance from the raw materials employed is not so great as to make it cheaper to transport the coal.

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* Cotton manufacture also requires a moist climate, such as is found in Lancashire.

As further instances illustrating the dependence of population on productions—cases directly linked up with the horizontal and vertical distribution of plants—may be mentioned the large towns of the North Pacific coast of the United States, which flourish on the trade in **timber** obtained from the afforested slopes of the Cascade Mountains and the Sierra Nevada ; and also the significant fact that in the Alps the upper limit at which **grain** can be grown, and the elevations to which human settlements reach, are practically the same.

Dependence of population on geographical position.—A population map of the world shows that humanity is most closely massed together near the mouths of certain great rivers : the Yang-tse-Kiang, the Hoang Ho, the Ganges, the Nile, etc.—in all cases on extensive **alluvial plains** or deltas (pp. 187 and 189). It is to be noticed, also, that on the alluvial flats of the Meuse, Rhine, Po and other rivers in Europe, such as those of the Thames, Clyde and Mersey in Britain and the rivers of the Ganges delta in India, the population is markedly denser than near the mouths of rivers which have not laid down these rich and fertile soils. It is thought that in ancient times such alluvial flats were the centres of civilisation, and it has been surmised that it was on the Mesopotamian Plain at the head of the Persian Gulf that civilisation actually originated and that wheat was cultivated first. However, in such questions notice must be taken of the outward growth of deltas, the protection against storm waves which an up-river site possesses, and to its strategical importance.

The sites of towns.—Since in primitive states the essential conditions for permanent human settlement must have been a supply of fresh water, shelter from stormy winds, and the means of growing food, the almost invariable selection of sites on flat fertile ground

along the course of a river or near a spring is easily understood. Whether the settlement grew at length to form a village, a town, or a city, naturally depended upon the possession of special advantages in addition to these essentials. Among such advantages, ease of communication with the surrounding country or neighbouring states must have been of great and increasing importance, as trading developed and made the produce of other settlements and countries available by exchange.

In India, ease of communication in olden days was of great importance to pilgrims visiting the holy places of the country—especially those along the Ganges from its sources to the sea. And it is to be remembered that the sites of many Indian towns—*e.g.* Benares, Allahabad, Hardwar—owe their establishment to the fact that they have grown on sites which are considered of great sanctity.

To a commercial community any place which was specially convenient for the loading or unloading of ships (*e.g.* at the **upper limit of navigation** on a river, or at the point where a river leaves a lake), or where for any other reason a redistribution of transported goods was necessary or advantageous, would form a natural nucleus of population. Hence the original positions of many English towns (*e.g.* Newcastle-on-Tyne).*

In Bengal the site of Tribeni appears to have been an early riverain port of the Hooghly, but as the river changed its course the town of Chinsurah grew up, and this in turn, owing partly to difficulties of navigation, has given place to Calcutta.

A convenient ford would often account for much early development, and when, later, it became necessary to replace the ford by a bridge, the corporate effort required would, as is usual with corporate effort, encourage the growth of the town. **Bridge towns** are consequently common, and have attained the greatest importance where, as in the case of London, the position of the bridge coincided with the upper limit of navigation.

Of even greater consequence than a ford would be easy access to river valleys, or a position on the coast conveniently situated for intercourse with other lands. The gaps at the heads of valleys form natural gates (Figs. 24 and 39), which join valley to valley to form a net-work of highways throughout the country. The growth of the town Calicut (and Beypore) on the Malabar coast facing the Palghat Gap—the only break in the scarp of the Western Ghat between Cape Comorin and the Tapti river—was natural. Clearly, other circumstances being favourable, a position on which many important valleys converge is an ideal site for a town. Such **confluence-towns** are illustrated by Allahabad,Goalundo and others in India, and by Reading, Oxford, Coblenz, Lyons, and St. Louis, in England and other countries.

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* As larger ships became common these towns would naturally be superseded in many cases by new towns lower down the river, where the water was deeper.

The commercial and strategical advantages of a position on a **strait** are obvious. They account for the existence of Constantinople, Gibraltar, Aden, and Messina. It is hardly necessary to mention the importance of towns like Port Said and Panama on canals which are international highways between large seas and oceans.

It is an instructive exercise to examine the positions of, say various **European capitals,** in the light of such considerations as those just referred to, and with the help of good orographical maps. *London* is thus seen to have had the initial advantages of an alluvial flat not liable to flooding ; of a bed of gravel supplying good water in plenty ; of a position at the head of navigation which could easily be bridged ; of a river valley branching in many directions and cutting through ranges of hills, giving access to the heart of the country and even communicating with rivers (*e.g.* the Severn) leading to other seas ; of a position facing a great population and the mouth of a great river on the continent ; of an estuary capable at the same time of admitting large ships and of affording protection from attack by sea. Though other positions in England possessed certain of these advantages in larger measure, only London possessed them all, and therefore grew in wealth, importance and population at a greater rate than its rivals.

An attentive study of the position of *Paris* will show its superiority for example, to Rouen, in respect of the river valleys it commands—avenues to Holland, Belgium, Germany, Switzerland, and Italy, besides south-eastern France. Again, *Marseilles*, which by the way, avoids the risk of inundation by its position to the east of the Rhone delta, has manifest advantages not possessed by Lyons on the one hand or Toulon on the other. Similarly, for Asiatic capitals or important towns, Calcutta, Bangkok, and Pekin may be considered with any other town which might prove a rival if endowed with certain advantages. Examples might be multiplied indefinitely.

As a final instance of the influence of geographical position on density of population may be mentioned the fact that in the circumpolar regions, it is apparently the length of the darkness of winter (which prevents hunting and fishing), rather than the great cold, which fixes the limit of human settlement.

It is certain that the distribution of mankind over the earth has been modified considerably by that of certain insects which are responsible for the spread of various **diseases.** Sleeping sickness, carried by a tsetse fly, has rendered many fertile tracts of tropical Africa uninhabitable ; and malaria, spread by a species of mosquito, is believed by some authorities to have been a material cause in the fall of ancient Greek civilisation.

EXERCISES ON CHAPTER XVII

1. Scotland presents an admirable example of the effects of a country's physical geography on the industries of its inhabitants. Prove this statement.

2. Explain how climatic differences affect the occupations and distribution of the peoples living (*a*) in south and east Asia, (*b*) in central Asia, and (*c*) in north Asia.

3. Show how the natural productions change as we proceed from south to north (*a*) from Java by Japan to the Behring Straits, and (*b*) from Cuba by Toronto to Hudson Bay. Account for the variation in each case.

4. Indicate the effects which the *position* and the *build* of either Australia or India or Spain have had upon its climate, productions, the density of its population, and its trade.

5. Explain fully why, in India, contrary to the general rule, the coalfields portion is less thickly populated than the manufacturing areas.

6. " The settlements of man are less dependent on physical conditions than in former times." From your knowledge of India show how you can justify this statement. Deal fully with any one instance.

7. Explain fully : *deciduous forest, pine forest,* and *jungle.* Mention some countries in which examples of each may be found, and name some of the wild animals living there.

8. Compare the occupations of the Esquimo with those of the natives of Patagonia, and the life of the inhabitants of central Africa with that of the inhabitants of central Australia.

9. What reasons can you give for the districts of 24 Parganas, Rajshai, and Muzaffarpur, being thickly populated as compared with Ranchi, Mirzapur, and Darjeeling?

10. Indicate the influence of climate in determining (*a*) the parts of the world inhabited by nomadic races, (*b*) the wheat growing areas of northern India, (*c*) the regions of large coniferous forests in the Himalaya.

11. Taking Europe and Africa as one land mass, compare its physical features, climatic zones, and characteristic animals and plants with those of the continent of America (North and South).

12. Show how the distribution of the population in the Punjab is related to the natural resources of the country, where these can be improved by irrigation.

13. State carefully the situations of Quetta, Peshawar and Lahore, and point out how their growth has been aided by their situation.

14. Explain, as fully as you can, why the lowland regions of the temperate zone are the most suitable for habitation by civilised man. Give examples illustrating your answer.

15. Elevation has an important geographical effect on vegetation, animal life and human occupations. Illustrate this effect by reference to one of the great highland areas of the world.

16. At what points on navigable rivers are towns likely to spring up? Give reasons. Illustrate by examples from rivers in the British Empire.

17. Towns frequently occur at the following places: (*a*) at the lowest points at which a river is bridged, (*b*) where two rivers join, (*c*) at the head of an estuary. Name two towns to illustrate each of these cases, and describe the position and importance of each town you name. What has been the effect of modern developments in shipping upon the class of towns mentioned in group (*c*)?

18. Name the chief wheat-producing areas of the world, and in regard to each give the time at which the harvest occurs, and the reasons why the harvest comes at the particular time.

19. State carefully which portions of Asia are most thickly populated, and which portions are most thinly populated, and account for the facts.

20. Discuss briefly the chief geographical features which determine the occupations of a people and the density of population. Illustrate by reference to definite regions.

21. What are the characteristic features to be remembered about the animal and vegetable life of (*a*) the Cold Regions, and (*b*) the Tropics? Mention the chief countries belonging to each region . Show by examples from these regions that the distribution of deciduous forests and evergreen woods is determined by altitude as well as by latitude.

22. Where are the grass lands found in Asia? How do you explain this? What is the chief occupation of the people on the great grass lands of Asia? Why?

23. Contrast the distribution of population in Bihar with that of the population in Bengal. What geographical or economic conditions explain the difference?

24. In what parts of the world do we still find true nomadic tribes? Show how their manner of life is controlled by their environment.

25. It has been stated that the plains are more thickly peopled than other portions of the earth's surface. Taking as illustrations the *great* plains of the earth, discuss the truth of this statement.

26. Account for the distribution of man as stated in the extract below, showing, by references to any good examples, how far it is true:

"Outside the monsoon region the belt of temperate forests (largely cleared) is by far the most densely inhabited part of the world. The desert and the tropical forests are almost as uninhabited as the tundras. The pampas and the prairies are rapidly growing in population."

27. What parts of Europe and Asia are still inhabited by people who make seasonal migrations? State the conditions which necessitate these movements.

28. Arid plains and steppes are found in their greatest extent either in the trade-wind belts or in vast continental interiors. Wherever they occur they present the same characteristics of land surface and natural products, and impose on their inhabitants similar habits and modes of life.

Give briefly the reasons for the occurrence of these areas in the regions mentioned ; state the characteristics referred to, and show how environment has influenced the homes and settlements of the people.

29. Choose any *three* of the following : Singapore, Aden, Trincomalee, Zanzibar, Hong Kong, New York, London, and examine their situation from the point of view of (*a*) communications, (*b*) history, (*c*) defence.

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